U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-267 551

Gaseous Emissions from Unregulated Mobile Sources

Michigan Univ., Ann Arbor. Dept of Environmental & Indus Health

Prepared for

Environmental Protection Agency, Ann Arbor, Mich.

Oct 76

PB 267 551

Motor Vehicle Emission Lab 013967
LIBRARY

Gaseous Emissions from Unregulated Mobile Sources

Final Report

by
DONALD E. ZINGER
LAWRENCE H. HECKER

October 1976

Prepared for

Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency
Ann Arbor, Michigan
Grant No. R-803568-01-0

THE UNIVERSITY OF MICHIGAN 1817

School of Public Health
Department of Environmental and Industrial Health

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Gaseous Emissions from Unregulated Mobile Sources			5. Report Date October 1976
			6.
7. Author(s) Donald E. Zinger, Lawrence H. Hecker			8. Performing Organization Rept. No.
9. Performing Organization Name and Address University of Michigan School of Public Health Department of Environmental and Industrial Health Ann Arbor, Michigan 48104			10. Project/Task/Work Unit No.
			11. Contract/Grant No. EPA-R-803568-01-0
12. Sponsoring Organization Name and Address Emission Control Technology Division Mobile Source Air Pollution Control- U.S. EPA 2565 Plymouth Road Ann Arbor, Michigan 48105			13. Type of Report & Period Covered Final Report
			14.
15. Supplementary Notes			

16. Abstracts

The impact of gaseous emissions are determined for unregulated mobile sources: farm equipment, merchant vessels, locomotives, lawn and garden tools, snowmobiles, outboard motors, and transport refrigeration units. All but farm equipment and snowmobiles appear to have negligible impact on total air burden. Future impact of these sources in certain areas are discussed. The current emission rates of each category are tabulated and compared to other emissions from both mobile and stationary sources in the studt area. As significance of these unregulated source will increase, projections are made as to the expected increase of emissions from each source category through 1980. Computer programs with instructions to estimate the rates in any Air Quality Control Region are given.

17. Key Words and Document Analysis. 17a. Descriptors

Air Pollution
Exhaust Gases
Small Engines
Agricultural Machinery
Snow Vehicles
Computation

17b. Identifiers/Open-Ended Terms

Unregulated Emissions
Air Quality Control Region

17c. COSATI Field/Group

18. Availability Statement Unlimited Release	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 291
	20. Security Class (This Page UNCLASSIFIED	22. Price A13 -A01

GASEOUS EMISSIONS FROM UNREGULATED MOBILE SOURCES

by

Donald E. Zinger
Lawrence H. Hecker

FINAL REPORT

Grant No. R-803568-01-0

Prepared for

Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency
Ann Arbor, Michigan

October 1976

The University of Michigan
School of Public Health
Department of Environmental & Industrial Health
Ann Arbor, Michigan 48109

FOREWORD

The project for which this report constitutes part of the end product was iniated on August 1, 1975, under EPA Grant No. R-803568-01-0, also known as The University of Michigan Account No. 013967.

The Project Officer of the Environmental Protection Agency was William H. Houtman, whose contributions and assistance were greatly appreciated. The offices of the sponsoring agency (EPA) are located at 2565 Plymouth Road, Ann Arbor, Michigan 48105.

A major part of this research involved obtaining a wide variety of information. Some of it was unpublished and some consisted of opinions and estimations from persons knowledgeable in that particular area. Officials of federal, state and local governments, representatives of industry, industrial trade associations, and researchers from universities and private organizations all provided valuable assistance without which this project could neven have been completed.

The initial contacts with the manufacturers of some of the vehicles and equipment which are investigated were made with a degree of hesitation because it was not known how cooperative they would be in regards to a subject as controversial as air pollution. But, with a few exceptions, they were very helpful. The prevailing attitude seemed to be that if their product was being analyzed as a source of air pollution, then it would be in their best interests to have it done as accurately as possible.

ABSTRACT

The impact of gaseous exhaust emissions are determined for the following categories of mobile sources which are currently not covered by national emission regulations: 1) farm equipment, 2) merchant vessels, 3) locomotives, 4) lawn and garden implements, 5) snowmobiles, 6) outboard motors, 7) transport refrigeration units, and 8) helicopters.

The results show that farm equipment can be responsible for a significant portion of the total oxides of nitrogen and carbon monoxide emissions in agricultural communities. Snowmobile engines emit a substantial amount of unburned hydrocarbons during the winter months in areas of their intense use. At the present time emissions from merchant vessels, locomotives, lawn and garden implements, outboard motors, and transport refrigeration units do not appear to contribute significantly to the total air pollution burden in the regions studied, but may be significant in other localized areas. In future years merchant vessels, lawn and garden implements, and outboard motors are projected to be significant polluters of HC and CO in certain areas predicted to be exceeding the primary ambient air quality standards. Helicopters are concluded to be relatively low emitting sources in all areas of the country.

The current emission rates of each category are tabulated and compared to other emissions from both mobile and stationary sources in the study area. As stricter emission standards on regulated sources continue to be implemented, the relative significance of these unregulated sources

will increase. Therefore, projections are made as to the expected increase of emissions from each source category through 1990.

Realizing that the amount of pollutant emitted by one of the source categories in a particular region does not always indicate the severity of its emissions in other parts of the country, generalized computer programs are developed. These programs permit the estimation of each category's present and future mass emission rates in any Air Quality Control Region in the country. Complete instructions on the use of these programs are included.

TABLE OF CONTENTS

FOREWORD ii

ABSTRACT iii

LIST OF TABLES viii

LIST OF ILLUSTRATIONS xi

LIST OF APPENDICES xii

INTRODUCTION 1

PART

1. FARM EQUIPMENT 8
    - Estimation of Emissions in a Selected AQCR
        - Equipment Population in the AQCR
        - Average Usage
        - Average Engine Size
        - Average Engine Load Factor
        - Emission Factors
        - Base Year Emissions
    - Projected Growth Analysis
    - Predictive Computer Program
    - Comparison with Other Air Pollution Sources

2. MERCHANT VESSELS 47
    - Estimation of Emissions in a Selected AQCR
        - Hours of Operation in the AQCR
        - Average Engine Size
        - Average Engine Load Factor
        - Emission Factors
        - Base Year Emissions
    - Projected Growth Analysis
    - Predictive Computer Program
    - Comparison with Other Air Pollution Sources

3. LOCOMOTIVES 70
Estimation of Emissions in a Selected AQCR
Hours of Operation in the AQCR
Average Engine Size
Average Engine Load Factor
Emission Factors
Base Year Emissions
Projected Growth Analysis
Predictive Computer Program
Comparison with Other Air Pollution Sources
4. LAWN AND GARDEN IMPLEMENTS 99
Estimation of Emissions in a Selected AQCR
Implement Population in AQCR
Average Implement Usage
Average Engine Size
Average Engine Load Factor
Emissions Factors
Base Year Emissions
Projected Growth Analysis
Predictive Computer Program
Comparison with Other Air Pollution Sources
5. SNOWMOBILES 123
Estimation of Emissions in a Selected AQCR
Hours of Operation in the AQCR
Emission Factors
Base Year Emissions
Projected Growth Analysis
Predictive Computer Program
Comparison with Other Air Pollution Sources
6. OUTBOARD MOTORS 142
Estimation of Emissions in a Selected AQCR
Outboard Motor Population in the AQCR

Average Usage
Average Engine Size
Emission Factors
Base Year Emissions
Projected Growth Analysis
Predictive Computer Program
Comparison with Other Air Pollution Sources

7. TRANSPORT REFRIGERATION UNITS 166

Estimation of Emissions in a Selected AQCR
Unit Population in AQCR
Average Usage
Average Engine Size
Average Engine Load Factor
Emission Factors
Base Year Emissions
Projected Growth Analysis
Predictive Computer Program
Comparison with Other Air Pollution Sources

8. HELICOPTERS 195

Estimation of Emissions in a Selected AQCR
Hours of Operation in the AQCR
Emission Factors
Base Year Emissions

DISCUSSION 205

IMPACT ASSESSMENT IN REGIONS PREDICTED TO EXCEED PRIMARY AMBIENT AIR QUALITY STANDARDS 216

APPENDIX 221

LIST OF REFERENCES 270

LIST OF TABLES

1. Estimated Power Farm Equipment Population in the North Central Iowa AQCR, 1973 16
2. Estimated Use of Rented Combines in the AQCR 20
3. Tractor Emission Factors 26
4. Non-tractor Farm Equipment Emission Factors 27
5. Emissions from Farm Equipment in the North Central Iowa AQCR, 1973 29
6. Projected Farm Equipment Growth Rates 35
7. Emissions Inventory for the North Central Iowa AQCR, 1976 44
8. Vessel Traffic on the Waterways of the New Jersey-New York-Connecticut AQCR, 1973 51
9. Hours of Vessel Operation in the New Jersey-New York-Connecticut AQCR, 1973 53
10. Estimated Vessel Duty Cycles for Harbor Operation . . 56
11. Merchant Vessel Emission Factors 60
12. Emissions from Merchant Vessels in the New Jersey-New York-Connecticut AQCR, 1973 61
13. Vessel Parameters According to Port Type 65
14. Emissions Inventory for the New Jersey-New York-Connecticut AQCR, 1976 68
15. Railroad Companies Operating in the Chicago AQCR in 1973 74
16. Locomotive Operation by Class I Railroads in the Chicago AQCR, 1973 78
17. Estimated Hours of Locomotive Operation in the Metropolitan Chicago AQCR, 1973 81
18. Locomotive Emission Factors 83

19. Emissions from Locomotives in the Metropolitan Chicago AQCR, 1973 84
20. Emissions Inventory for the Metropolitan Chicago AQCR, 1976 97
21. Estimated Lawn and Garden Implement Population in the United States, 1974 106
22. Estimated Lawn and Garden Implement Population in the Detroit-Port Huron AQCR, 1974 106
23. Emission Factors for Lawn and Garden Implements . . . 112
24. Emissions from Lawn and Garden Implements in the Detroit-Port Huron AQCR, 1974 113
25. Emissions Inventory for the Metropolitan Detroit-Port Huron AQCR, 1975 Season 121
26. Days of Snowmobile Use in the Central Michigan AQCR, 1973-74 Season 128
27. Hours of Snowmobile Use in the Central Michigan AQCR, 1973-74 Season 129
28. Snowmobile Emission Factors 131
29. Emissions from Snowmobiles in the Central Michigan AQCR 1973-74 Season 132
30. Emissions Inventory for the Central Michigan AQCR, 1974-75 Season 140
31. Typical Outboard Motor Duty Cycles for Four Horsepower Categories 154
32. Composite Mass Emissions of Four Outboard Motors . . 154
33. Outboard Motor Emission Factors 156
34. Emissions from Outboard Motors in the Detroit-Port Huron AQCR, 1974 157
35. Emissions Inventory for the Metropolitan Detroit-Port Huron AQCR, 1975 Season 164
36. Estimated Refrigerated Vehicle Population in the United States, 1974 173
37. Estimated Transport Refrigeration Unit Population in the United States, 1974 173

38. Estimated Operating Hours of Transport Refrigeration Units in the Los Angeles AQCR, 1974 175

39. Calculation of a Typical Load Factor for a Trailer Refrigeration Unit 178

40. Calculated Emission Factors for Diesel Powered Transport Refrigeration Units 181

41. Calculated Emission Factors for Gasoline Powered Transport Refrigeration Units 182

42. Emissions from Transport Refrigeration Units in the Los Angeles AQCR, 1974 183

43. Emissions Inventory for the Metropolitan Los Angeles AQCR, 1976 193

44. Hours of Helicopter Operation in the New Jersey-New York-Connecticut AQCR, 1973 200

45. Typical Helicopter Duty Cycles 200

46. Helicopter Emission Factors 203

47. Emissions from Helicopters in the New Jersey-New York-Connecticut AQCR, 1973 204

48. Summary of Emissions from Unregulated Mobile Sources 206

49. Simplified Equations for Estimating Emissions 213

50. Hydrocarbon Emissions in Regions Predicted to Exceed Oxidant Standard 218

51. Carbon Monoxide Emissions in Regions Predicted to Exceed CO Standard 220

LIST OF ILLUSTRATIONS

1. Projected Farm Tractor Population in the United States. 32
2. Sample Output of Farm Equipment Computer Program . . . 39
3. Projected Farm Equipment Emissions: HC 40
4. Projected Farm Equipment Emissions: CO 41
5. Projected Farm Equipment Emissions: NO_x 42
6. Projected Farm Equipment Emissions: SO_x 43
7. Sample Output of Merchant Vessel Computer Program . . . 66
8. Sample Output of Locomotive Computer Program 91
9. Projected Locomotive Emissions: HC 92
10. Projected Locomotive Emissions: CO 93
11. Projected Locomotive Emissions: NO_x 94
12. Projected Locomotive Emissions: SO_x 95
13. Sample Output of Lawn and Garden Implement Computer Program 118
14. Projected Lawn and Garden Implement Emissions: HC . . 119
15. Projected Lawn and Garden Implement Emissions: CO . . 120
16. Sample Output of Snowmobile Computer Program 137
17. Projected Snowmobile Emissions: HC 138
18. Projected Snowmobile Emissions: CO 139
19. Sample Output of Outboard Motor Computer Program . . . 161
20. Projected Outboard Motor Emissions: HC 162
21. Projected Outboard Motor Emissions: CO 163
22. Sample Output of Transport Refrigeration Unit Computer Program 189
23. Projected Transport Refrigeration Unit Emissions: HC . 190
24. Projected Transport Refrigeration Unit Emissions: CO . 191
25. Projected Transport Refrigeration Unit Emissions: NO_x. 192

LIST OF APPENDICES

1. Farm Equipment 221
2. Merchant Vessels 233
3. Locomotives 241
4. Lawn and Garden Implements 250
5. Snowmobiles 256
6. Outboard Motors 260
7. Transport Refrigeration Units 264

INTRODUCTION

> Between 1940 and 1970, the total nationwide emissions of all the major regulated air pollutants grew substantially. Since 1970, however, air pollution control programs appear to be stemming that growth. These improvements are encouraging and have obviously benefited the nation's health and welfare. Yet undesirably high levels of the major air pollutants continue to occur at many locations. Only about one-third of the nation's 247 Air Quality Control Regions are fully meeting the health protection ambient standards for all pollutants at present.
>
> From the Sixth Annual Report of the U.S. Council on Environmental Quality. (December, 1975)

Today most major sources of air pollution are known, and steps are being taken by federal, state and local governments to reduce their emissions. Air pollution sources may be divided into two groups: stationary and mobile sources. At the present time the only mobile sources which are regulated by national emission standards, or have standards which are expected to take effect in the next few years, are light duty vehicles (automobiles), heavy duty vehicles (trucks and buses), and aircraft. Also, standards have recently been proposed for motorcycles. Obviously, by their sheer numbers, cars and trucks account for the major portion of mobile source air pollution. But as new models continue to reduce emissions, and older models are scrapped, a state of diminishing returns may be reached. Further incremental improvements will come only with great technological and economic expense. When this happens a wiser plan of action might be to establish emission limitations on other types of mobile sources. Since essentially all mobile sources utilize internal combustion engines, the emission control technology which has already proved successful on automobile and truck engines can be adapted to achieve significant reductions in the total amount of pollutants released by these sources.

The purpose of this report is to assess the impact of emissions from eight categories of mobile sources which are currently unregulated, and to develop the means by which others can easily and accurately perform similar impact assessments. The categories are:

1. Farm equipment
2. Merchant vessels
3. Locomotives
4. Lawn and garden implements
5. Snowmobiles
6. Outboard motors
7. Transport refrigeration units
8. Helicopters

Although none of these sources is as ubiquitous as the automobile, their use is often highly localized. Therefore, emissions are determined for geographic areas defined by the United States Environmental Protection Agency as Air Quality Control Regions (AQCR). The nation is divided into 247 Air Quality Control Regions, each composed of a group of counties or portions of counties.

Emissions are estimated on the basis of a mass emission rate, generally tons per year of each pollutant. Where seasonality is a factor, as for example with snowmobiles, the time frame is reduced to tons emitted over the length of an average season. Of course, an analysis of mass emission rates does not account for 1) the dispersal and movement of pollutants, 2) various chemical reactions of the pollutants in the atmosphere, and 3) the process by which pollutants are removed from the atmosphere, such as gravity and precipitation. These factors, which depend on topography and meteorological conditions, would be needed to relate the emission rates of all pollution sources in an area to the quality (or pollutant concentrations) of the ambient air. The dispersion and chemical reaction characteristics of pollutants are still not fully understood and they are not covered in this analysis. Furthermore, it is important to realize that a study of mass emissions is not easily related to effects on human health and well being. Health effects of air pollution are a function of a person's exposure time and the pollutant's concentration in the ambient air. Although it is beyond the scope of this research, the next logical step is to integrate the results presented here into an analysis of air quality.

For each of the eight categories emission rates are determined for the pollutants that are the major components of internal combustion engine exhaust gas: total hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x). In addition, sulfur oxides (SO_x) emissions are determined for those categories which use large diesel engines: farm equipment, merchant vessels, and locomotives. The estimates cover only exhaust gas emissions, any additional hydrocarbons released by fuel evaporation are not included, because there is insufficient data on typical evaporation rates.

The report is composed of eight parts, one for each category. Each part is divided into four sections. The first section is the estimation of emissions in a selected Air Quality Control Region. An attempt is made to choose a region in which the source has a high usage rate. For example, Chicago is generally acknowledged as the center of railroad activity, so locomotive emissions are analyzed in the Metropolitan Chicago AQCR. For sources that are more equally distributed, such as lawn and garden implements, the selection is not as clear cut but, in general, the criteria are a large category population, high annual or seasonal usage, and the accessibility of data. The rationale is that if emissions from a particular source are found to be relatively insignificant in a region of its intense use, then that source possibly is not a significant polluter in any other region.

After the selection of an AQCR is made, the base year of the analysis is chosen depending on the most recent year for which information is available. In all cases the base year is either 1973 or 1974.

The remaining part of the first section develops the parameters needed to estimate the mass emissions released by the source category in the AQCR for the base year (or season). The methodology differs somewhat for each category, but generally the category population in the region is determined, as well as the average usage rate of a single unit in terms of hours of use per week, per month, etc.. The average engine size and average engine load factor are also determined.

The final parameters are engine emission factors. An emission factor indicates the average amount of a pollutant released by a single engine. Most engine exhaust tests measure mass emissions per unit time (grams/hour). But this value can only be compared to emission rates of engines of similar size (horsepower). A more useful quantity is an emission rate that is brake specific (grams/horsepower-hour). Brake horsepower refers to horsepower developed at the flywheel. Of course, this parameter assumes emissions are linearly proportional to horsepower. Most of the emission factors for the types of engines used in these categories have already been established. With a few exceptions, the emission factors used in the following analyses are based on tests performed under the sponsorship of the U.S. Environmental Protection Agency by Southwest Research Institute. Although these tests were very limited and in no way can be considered as establishing baseline emissions, they provide valuable data for an initial study of these unregulated mobile sources. Other researchers have also measured emissions from some of these sources, and their results are discussed. But it was decided that whenever possible to use the Southwest Research Institute data. The consistent use of these data removes at least some of the variables inherent in emission testing.

The second section of each part attempts to project the growth (or decline) of emissions from the category. As mentioned, even though these sources may not emit a significant amount of pollution at the present time, as emission controls on regulated sources become more effective, the significance of unregulated sources will increase. By analyzing past trends of the category population a growth rate (positive or negative) is projected. In most cases it is a constant annual rate of increase, compounded yearly, and applies from the base year to 1990.

The third section of each part describes the generalized computer program which allows the estimation of mass emissions from the source category in any Air Quality Control Region in the country, for any year between the base year and 1990. The parameters used by the computer program are based on those developed in the first section. Parameters such as emission factors, average engine size, and load factors are considered independent of individual AQCR characteristics and, thus, are assigned constant values in the program. A user of the program is required to supply certain input data. Indicator parameters are developed which relate the population or usage of the source in a given AQCR to some readily obtainable data. The user must also choose a growth rate which may be positive, zero, or negative.

The computer program is designed to estimate emissions for Air Quality Control Regions, but it can also be used for an entire state or an individual county. The programs are written in Fortran IV, specifically for use on an IBM System 370 computer at The University of Michigan, but they are easily adaptable to other computers as well. The computer-generated plots used in this report are not a standard output of the program.

The fourth, and final, section of each part compares the estimated emissions of the source category in the selected Air Quality Control Region to mass emissions from other sources, both mobile and stationary, in the same AQCR. Information on other source emissions is compiled in the U.S. Environmental Protection Agency's National Emission Data System. Like the emissions calculated in this report, they are also based on broad assumptions and estimates. But it is important to realize that the absolute figures are not critical, but rather their relative values. The analyses presented on the following pages will provide the tool for government agencies to assess the impact of emissions from these unregulated mobile sources, now and in the future, and to begin to establish relative priorities in their pollution abatement programs.

PART 1

FARM EQUIPMENT

Farming in the United States is extremely energy intensive. Highly specialized machinery has replaced human and animal labor. Today there are over six million power farm machines in use [1]. The exhaust gases from these engines are often emitted in areas where there are relatively few other sources of air pollution. Even though the total air pollution burden of farming communities is low in comparison to urban areas, that portion caused by farm equipment may be substantial. For this reason an analysis of the amounts of exhaust emissions released by farm equipment engines is needed.

The most populous piece of equipment is the tractor, which is used to pull a variety of implements. If the pulled implement requires power, it often comes from the tractor's power take-off (PTO) system. Some pulled implements have auxilary engines. As the acreage of the average farm has increased, there has been a rapid proliferation of large, specialized machines, many of which are self-propelled. The most common are combines, forage harvesters, and windrowers. These machines, as well as tractors, have either gasoline or diesel powered engines. The use of propane gas in farm engines is declining, and it is not included in this analysis even though it is an important fuel in crop drying.

Emissions from aircraft used in agriculture, such as aerial spraying, also are not included here.

The following list specifies the types of farm equipment which are analyzed.

1. Tractors: the vast majority are wheeled, but crawler tractors are included; garden tractors are not
2. Combines: these versatile machines are used to harvest grain and bean crops; they are either self-propelled or pull type
3. Windrowers: sometimes called swathers, these machines cut and windrow small grain and hay; they can be either self-propelled or pull type
4. Pickup balers: some are self-propelled, but most are pull type
5. Forage harvesters: also called field choppers, these units can be either self-propelled or pull type
6. Miscellaneous engines: this includes numerous small engines used on farms, such as in sprayers, elevators, grinders, forage blowers, picker-shellers, as well as stationary engines used in irrigation, etc.

Estimation of Emissions in a Selected AQCR

Efficient agricultural planning requires an extensive information gathering network. Federal and state agencies compile an immense amount of farm related statistics. These can be used to accurately determine the amount of farming activity and related machinery in any part of the country. The criterion for selecting an Air Quality Control Region in which to analyze farm equipment emissions is that it must have a large equipment population. The first step in the selection process is to choose a state which meets this requirement. Iowa is recognized as one of the nation's leading agricultural states. It produces over 20% of the national corn crop and 17% of the soybeans [2,3,4]. Of greater relevance is the fact that Iowa has more tractors than any other state [5,6]. It follows that the selected AQCR should be in Iowa. The U.S. Census of Agriculture reports the number of major farm implements in use on a county basis. A census is taken every five years, most recently in 1974. However, at the time of this project 1974 data were still being compiled, so the 1969 census is used [6]. The region in Iowa with the greatest tractor population (over 50,000) is the North Central Iowa Air Quality Control Region. This is about one tractor for every 100 acres of farm land [7]. While it is impossible to categorically state that this region has a greater number of farm machines than any other in the country, it is certainly near the top. It includes the following counties in Iowa.

Butler
Cerro Gordo
Hamilton
Hancock
Mitchell
Webster

Floyd
Franklin
Grundy
Hardin
Humboldt
Kossuth
Winnebago
Worth
Wright

The North Central Iowa AQCR covers 8,360 square miles, and had a 1970 population of 303,000 people. There were 21,193 farms in 1969.

The base year of the analysis is 1973. Although equipment usage peaks in the spring and fall months, its "season" is nearly year round so annual emissions are studied. The parameters needed to estimate emissions from each type of farm equipment are determined in the following sections. They are:

1. Equipment population in AQCR
2. Average usage (hours per year)
3. Average engine size (horsepower)
4. Average engine load factor
5. Emission factors (grams of pollutant per horsepower-hour)

Equipment Population in the AQCR

Compared to the other categories in this report the data on regional farm equipment population are excellent. The Census of Agriculture lists the major types of farm machinery in every county. The only adjustment to be made is updating the 1969 data to the base year of 1973. The national farm equipment population, in general, has been decreasing over the past decade. This is due to the increasing size of farms, and the increasing size of equipment.

This trend is discussed at length in the section on growth analysis. The 1969 population is adjusted to 1973 levels by using annual estimates of machines on farms published in a farm equipment trade magazine [5]. The estimates are by types of equipment for the total U.S. and for each state. Assuming that the population change in the North Central AQCR is proportional to the Iowa population change, the following equation is used to estimate 1973 AQCR farm equipment populations.

$$\frac{\text{Equipment in AQCR, 1973}}{\text{Equipment in AQCR, 1969}} = \frac{\text{Equipment in Iowa, 1973}}{\text{Equipment in Iowa, 1969}}$$

The populations determined in this manner represent the total number of each equipment type. In order to accurately analyze emissions resulting from the use of these machines, the type of engine (gasoline or diesel), and in some cases, whether the unit incorporates an independent engine, must be known.

The composition of national tractor population is well documented. Two recent reports estimated the 1972 population to be about 69% gasoline, 31% diesel [8,9]. Since diesel tractors outsold their gasoline counterparts at a rate of five to one in 1973, that year's population is even more diesel oriented. Adding 1973 tractor sales data to the previous estimates, the composition of the 1973 U.S. farm tractor population is calculated to be 64.1% gasoline and 35.9% diesel powered. It is assumed that the North Central Iowa AQCR tractors, estimated to be 50,360 units in 1973, are also defined according to these percentages.

The Census of Agriculture lists the number of self-propelled combines in the AQCR in 1969. Unlike tractors, the number of self-propelled combines are increasing. Using the equation described above, the 1973 AQCR population of self-propelled combines is calculated as 5,830 units. The composition by engine type is also drastically changing. In 1969 less than 5% of self-propelled combines were diesel. However, by 1973 diesels were accounting for half of all combine sales. Of course, the percentages represented in sales do not equal the population percentages, and self-propelled combines are still predominantly gasoline. The 1973 population is estimated to be 85% gasoline and 15% diesel.

Pull type combines are less numerous than self-propelled models, and they are not included in the 1969 Census of Agriculture count. Fortunately, other data are available to permit reliable estimates. In 1973 30% of all combines on U.S. farms were pull types. Applying this percentage to the Iowa AQCR the 1973 pull type combine population is estimated to be 2,500 units. Not all of these are engine powered, however. In fact the majority are powered by tractor PTO, which are not of interest in an analysis of air pollution. The best estimate of the percentage incorporating an auxiliary engine can be obtained from the annual farm equipment product index published by a trade magazine [5]. Of all pull combine models listed approximately 25% are available with auxilary engines. The engines are all gasoline powered. These figures are used in the AQCR equipment population analysis.

The category of windrowers in the Census of Agriculture includes self-propelled and pull types. In 1964 only 25% of all windrowers in use were self-propelled, but sales were 90% self-propelled [11]. By 1973 pull types accounted for less than 7% of windrower sales. Since farm implements normally have long service lives, the 1973 windrower population is estimated as 65% self-propelled and 35% pull types. The 1969 regional population is updated to 1973 levels by substituting sales data into the proportionality equation rather than population data, as the latter were not available. This results in a 1973 AQCR windrower population (all types) of 3,540 units. All pull types are assumed to be PTO powered; hence, they are not considered here. Self-propelled windrowers are estimated to be 85% gasoline and 15% diesel powered.

The pickup baler is a very useful implement; one of every three farms in the AQCR reported owning a unit in 1969. Most are pull types using PTO. Only recently have self-propelled models been produced. From manufacturer's production statistics it appears that only about 10% of the balers have engines, nearly all of which are gasoline powered. Using these figures and updating the 1969 Census of Agriculture count to 1973, the number of pickup balers with engines (most auxiliary, a few self-propelled) in the AQCR is calculated to be 660 units.

The majority of forage harvesters also are pull type of PTO power. Between 1967 and 1973 the percentage of forage harvesters produced that were self-propelled rose from 6% to 10% [10]. Thus, the 1973 population is estimated as 7% self-propelled. The engine of a self-propelled harvester is large and they are almost all diesel powered. Therefore, the 1973 AQCR population of forage harvesters with engines (self-propelled only, 100% diesel) is estimated to be 130 units.

An estimation of the number of miscellaneous internal combustion engines used on farms is very tenuous. These engines are used for a wide variety of purposes which differ according to the type of farm, and in many cases the mechanical ingenuity of the farmer. The only source which attempts to estimate their numbers is a farm implement trade magazine [5]. It estimates over 1.1 million miscellaneous engines were used on U.S. farms in 1973, with 50,000 of these in Iowa. Using this figure and the percentage of Iowa farms included in the North Central AQCR (15%), the 1973 miscellaneous engine population is estimated to be 7,500 units. Since the majority are small horsepower, 90% are assumed gasoline and 10% diesel powered.

A summary of the 1973 farm equipment population in the North Central Iowa AQCR by implement and engine type is listed in Table 1.

Average Usage

As could be expected, estimates on the number of hours the average tractor is used vary considerably. They range from less than 300 to greater than 700 hours a year [8,9,12-15]. One conclusion that can be drawn about tractor usage is that it is a function of tractor age and engine size. Older machines of less horsepower are used less than newer, larger models. It is quite common for a modern farm to have two tractors: one old, one new. The newer one is used for major farming operations--plowing, tilling, planting and harvesting--while the older tractor performs less demanding odd jobs.

TABLE 1

ESTIMATED POWER FARM EQUIPMENT POPULATION IN THE NORTH CENTRAL IOWA AQCR, 1973

	Total	Gasoline	Diesel
Tractor	50,360	32,280	18,080
Combines, Self-propelled	5,830	4,960	870
Pull Type	625	625	--
Windrowers, Self-propelled	2,300	1,950	350
Balers, Self-prop. & Pull Type	660	660	--
Forage Harvesters, Self-prop.	130	--	130
Miscellaneous Engines	7,500	6,750	750

An analysis of air pollution requires the separation between gasoline and diesel powered tractors. Since older models tend to be relatively lower horsepower and gasoline fueled, usages by engine type are desirable. There are three sources of this information. A study done by Southwest Research Institute for the U.S. Environmental Protection Agency estimated mass emissions from farm equipment on a national scale [8]. A similar project, limited to farm tractors, was performed by International Harvester Co. [9]. Both studies derive an average usage based on an theoretical formula which relates usage to tractor age and engine size. Because they essentially use the same method the results are the same: about 290 hours annually for gasoline tractors, and about 490 hours for diesels.

The third source of tractor usage data is research done by the Agricultural Engineering Department of Michigan State University [15]. This study was aimed at investigating farm machinery accidents, but in the process determined very precise usage data. Done in 1971 the study randomly selected farms in a number of counties in Michigan and Ohio. Farmers were asked to keep log sheets recording their use of tractors and other farm machinery. Data from over 2,200 farms were collected and projected to statewide totals. When the data for total tractor usage by fuel type are divided by the number of tractors in each state the results are:

	Average Tractor Hours per Year	
	Gasoline Units	Diesel Units
Michigan	480	730
Ohio	370	660

These usage figures are significantly greater than those of SWRI and International Harvester. The differences may be accountable. First, the MSU study recorded the total engine operating time, not just the time the tractor was actually plowing, or harvesting. This is important, since pollutants are emitted whether the tractor is idling by the barn, fertilizing the crop, or pulling a wagon down a public road. Furthermore, the SWRI and IH estimates are not based on actual measurements of a large sample of tractors, and some of their reference material is well over ten years old. For these reasons the usage estimates in this analysis are weighted heavily on the MSU results.

Comparing tractor usage in Michigan and Ohio with that in Iowa is difficult, but some general statements can be made. The average farm size is greater in Iowa than in Michigan or Ohio [6]. This might mean more efficient tractor use, and more tractors per farm, both of which indicate less hours of use. Also, larger farms tend to own more specialized, self-propelled implements also resulting in less tractor use. Taking these factors into account the average annual usage of gasoline tractors in Iowa is estimated to be 340 hours per year, and for diesel tractors 600 hours per year.

There has been much less research on usage of non-tractor equipment, but their populations are lower, so estimates are not as critical. Usage estimates can be assumed equal for both gasoline and diesel equipment. Few farms have more than one windrower, for example, so usage is the same whether it is gasoline or diesel. Also, the range of horsepowers is not as large as that in tractors.

Estimates of self-propelled combine usage range from 50 to 150 hours per year [8,9,16]. The MSU study yields data which result in 136 hours per year (Ohio) and 103 hours per year (Michigan). The average annual usage of self-propelled combines in Iowa is estimated to be 120 hours per year.

Pull type combines can be expected to experience less use than self-propelled models. An estimate of 75 hours per year is made.

Self-propelled windrowers and forage harvesters can be used as much as 250 hours per year [16]. The figure for this analysis for each of these implements is 150 hours per year.

Pickup baler annual use is also highly variable. One estimate is 24 hours, another is 250 hours [8,16]. This analysis uses an estimate of 80 hours per year.

Miscellaneous engines may have high usage, such as for irrigation pumps. One source estimates 50 hours per year which is probably a minimum [8]. The estimate made here is 80 hours per year.

The final item related to farm equipment usage concerns rentals. The development of specialized implements allows very efficient crop management, but many farmers cannot afford to purchase these units. Therefore renting, leasing, and custom hiring (equipment is rented with an operator) are becoming more popular. There is minimal renting of tractors. Most rentals are of harvesting equipment, since it is often beneficial to rent a number of implements to insure a prompt harvest. The 1969 Census of Agriculture lists the following percentages of acres harvested for three major crops in Iowa by custom-work or rented machines: 1) corn, 7.1%; 2) soybeans, 9.8%; and 3) oats, 2.7%. The major implement used to harvest these crops is the self-propelled combine. If a conservative assumption is made that in 1973 each of the above percentages increased by one point, then the acres harvested by rented self-propelled combines in Iowa can be calculated.

The first step is to determine the effective field capacity, in acres per hour, of a combine. The following equation can be used [16].

Effective field capacity (acres/hr)
= (Avg speed x Implement width x Field efficiency)/825

Typical figures for a self-propelled combine are:

1. Average speed, 3 mph
2. Width of grain header (for soybeans and oats), 14 feet
3. Width of corn header (4 row, 3 ft. between rows), 10.5 feet per pass
4. Field efficiency, 70%

These figures result in typical field capacities of 3.56 acres per hour for soybeans and oats, and 2.67 acres per hour for corn.

The final step is to apply these estimates to each crop's harvested acreage in the North Central Iowa AQCR. Since 18.2% of Iowa's harvested cropland occurs in this region, the hours of combine operation this represents can be calculated. Table 2 lists the results.

TABLE 2

ESTIMATED USE OF RENTED COMBINES IN THE AQCR

Crop	Acres Harvested by Rental Combines	Effective Acres/Hr	Hours of Operation by Rented Combines
Corn	166,300	2.67	62,300
Soybean & Oats	161,300	3.56	45,300
			107,600

The total hours of operation is apportioned according to previous estimates: 85% gasoline units, 15% diesel units. These figures are included in the calculation of emissions from self-propelled combines in a following section. It should be noted that, if anything, these estimates are conservative. Data relating only to three major crops are used, applied strictly to self-propelled combine operation.

Average Engine Size

As with most of the other parameters, there is extensive information on the average tractor engine size, and much less for other types of powered farm equipment. The following estimates are chosen to represent the 1973 farm equipment population based on currently available data [1,5,8,9,10].

It is important to note that tractor engine ratings are always expressed as PTO horsepower. The emission factors, however, are brake specific. Hence, compensation is needed to calculate brake (flywheel) horsepower from PTO horsepower. It is generally agreed that the ratio is between 1.12 and 1.17 to one [8,9]. This analysis uses 1.15: 1 as the average flywheel horsepower to PTO horsepower ratio.

1. The average gasoline tractor is estimated to be 36.0 PTO hp
2. The average diesel tractor is 70.3 PTO hp
3. The average self-propelled combine is 90 hp

4. The average pull type combine is 30 hp
5. The average self-propelled windrower is 60 hp
6. The average pickup baler, pull type and self-propelled, is 50 hp
7. The average self-propelled forage harvester is 150 hp
8. The average miscellaneous farm engine is 35 hp, gasoline and diesel

Average Engine Load Factor

The emission factors cited in the next section are derived from emission tests on typical farm engines. The tests are conducted at various engine speed and engine load conditions. Ideally these conditions would represent an average duty cycle of the implement's actual operation. There is a thorough discussion of the determination of farm equipment duty cycles in the Southwest Research Institute report and it will not be repeated here [8]. A review of the literature yields estimates of average tractor engine load factors between 0.33 to 0.70 [9,12,14].

One possibly outdated study (1961) measured load for a wide variety of tractor activities [12]. As would be expected, plowing and discing loaded the engine the greatest amount (78 to 88% of capacity). The study concluded that an average load factor is about 0.50. This agrees with the tractor load factor developed by SWRI of 0.57, and the latter estimate is used in this analysis for both gasoline and diesel tractors.

Very little research has been done on engines used in non-tractor equipment. The function of most of these implements is specialized and they can be expected to operate near rated engine speed. Lacking any firm data the average load factor for all types of farm engines, other than tractors, is estimated to be 0.50.

Emission Factors

The most extensive emission tests on engines used in farm equipment were done by Southwest Research Institute [8]. Twelve engines were tested, each of which has an application in farm implements. Emissions from the eight diesel and four gasoline engines were measured and weighted according to a tractor duty cycle and to a cycle representative of powered farm equipment other than tractors. International Harvester Company also has published emission data on their tractor engines [9]. Generally, the results are comparable to those of SWRI.

To arrive at a composite emission factor to represent, say, hydrocarbon emissions from tractors, emission factors from each engine in that category are weighted in an appropriate manner. Ideally the weighting factors would represent that engine's relative abundance in the total tractor population. Lacking this explicit information, estimates must be attempted. Those developed by SWRI are admittedly arbitrary. Weighting factors used to derive the following emission factors are based on three criteria. First, farm equipment manufacturers are ranked according to total annual sales. Stockholder reports are used, and even though the type of information differs somewhat, a definitive ranking is possible. According to the

1973 total revenue from sales of agricultural equipment the major U.S. manufacturers are, in relative ranking:

1. John Deere & Co.
2. International Harvester Co.
3. Massey-Ferguson Ltd.
4. J. I. Case Co.
5. Allis-Chalmers Corp.
6. White Motor Corp.

Note: It is not possible to determine Ford Motor Co.'s ranking because their tractor sales include construction and industrial units.

These rankings do not necessarily indicate relative production of farm implements, nor the abundance of units currently in use. They can be used only as one possible criterion from which to estimate engine weighting factors.

Another criterion is obtained from the Michigan State University study of farm machinery use and safety [15]. The findings include the fraction of total tractor usage hours accumulated by make of tractor in the survey area (randomly selected farms in Michigan and Ohio). The results agree very closely with the rankings from annual sales. They are based on data from tractors only.

The third source of useful information is found in a farm equipment trade magazine [5]. An annual issue lists implement specifications of each manufacturer's models. The number of models on which a given engine is used is a further indication of the engine's popularity, at least in the current market.

The information gathered from the above three sources is used to derive weighting factors for the engines tested by SWRI. They are gross estimations to be sure, but they will have to suffice until a detailed census of the farm equipment population is undertaken.

Of the twelve SWRI diesel test engines five are commonly used in tractors. They are listed in Table 3 with the population weighting fraction and the composite emission factors for HC, CO, NO_x and SO_x. Sulfur oxides data are based on calculations of the sulfur content of fuel. SWRI assumed typical diesel fuel is 0.22% sulfur by weight and all is oxidized to SO_2 by the combustion process.

The same assumption is made for gasoline with a typical sulfur content of 0.043%. Only two of the gasoline engines tested by SWRI are used in tractors, and one of these, the Case engine, was tested under abnormal operating conditions. Thus, it is decided to include results from the International Harvester tests on a gasoline engine from a 58 PTO hp tractor. They are listed in Table 3 with heaviest weighting assigned to the IH engine, and very low weighting given to the questionable Case engine results.

All eight of the diesels tested by SWRI are included in calculations of composite emission factors to be used for non-tractor farm equipment (combines, windrowers, etc.). The estimated population weighting factors are primarily based on the relative number of engines of that make currently available on powered farm implements. Table 4 lists the relevant data.

Emission factors representing gasoline farm implements are cal-

TABLE 3

TRACTOR EMISSION FACTORS

Engine	Estimated Weighting Fraction	Grams per Horsepower-hour							
		Engine Emission Factor				Calculation of Composite E.F.			
		HC	CO	NO_x	SO_x	HC	CO	NO_x	SO_x
I. Diesel Powered									
Deere	0.40	2.93	2.66	5.86	0.91	1.17	1.06	2.34	0.36
Internat'l Harv.	0.25	2.23	4.67	8.51	0.86	0.56	1.17	2.13	0.22
Perkins	0.14	0.39	3.22	10.7	0.80	0.05	0.45	1.50	0.11
Detroit Diesel	0.14	0.62	1.49	23.3	0.90	0.09	0.21	3.26	0.13
Allis Chalmers	0.07	0.51	2.66	10.8	0.87	0.03	0.19	0.76	0.06
	1.00					1.90	3.08	9.99	0.88
II. Gasoline Powered									
Internat'l Harv.	0.60	2.77	163.	7.76	--	1.66	97.8	4.66	--
Ford	0.35	5.36	129.	7.14	0.23*	1.88	45.2	2.50	0.12
Case	0.05	6.73	268.	2.22	0.27*	0.34	13.4	0.11	0.13
	1.00					3.88	156.	7.27	0.25

* Since SO_x data are only available for two gasoline engines, a weighting fraction of 0.50 is used for each.

TABLE 4

NON-TRACTOR FARM EQUIPMENT EMISSION FACTORS

Engine	Estimated Weighting Fraction	Grams per Horsepower-hour							
		Engine Emission Factor				Calculation of Composite E.F.			
		HC	CO	NO_x	SO_x	HC	CO	NO_x	SO_x
I. Diesel Powered									
Deere	0.30	3.21	2.98	5.54	0.94	0.96	0.90	1.66	0.28
Internat'l Harv.	0.25	2.49	5.56	8.22	0.90	0.62	1.39	2.06	0.23
Perkins	0.15	0.43	3.81	9.83	0.82	0.06	0.57	1.47	0.12
Allis Chalmers	0.10	0.55	3.19	10.8	0.90	0.06	0.32	1.08	0.09
Detroit Diesel	0.10	0.71	1.81	23.5	0.93	0.07	0.18	2.35	0.09
Caterpillar	0.06	0.09	0.90	4.78	0.87	0.01	0.05	0.29	0.05
Onan	0.02	1.50	4.13	6.23	1.30	0.03	0.08	0.12	0.03
Mercedes Benz	0.02	1.03	3.76	2.85	1.10	0.02	0.08	0.06	0.02
	1.00					1.83	3.57	9.09	0.91
II. Gasoline Powered									
Wisconsin	0.50	9.26	293.	5.41	0.34	4.63	147.	2.71	0.17
Ford	0.35	5.91	144.	6.85	0.24	2.07	50.4	2.40	0.08
Hercules	0.15	5.96	190.	3.93	0.26	0.89	28.5	0.59	0.04
	1.00					7.59	226.	5.70	0.29

culated as shown in Table 4. Three of the four SWRI gasoline engines are common in the current market (the Case engine is not).

Base Year Emissions

Exhaust emissions from tractors are estimated by entering the appropriate values into the following equation.

(Tractor population in AQCR) x (Avg hours of use/year)
x (Avg PTO hp) x (Flywheel hp/PTO hp) x (Avg load factor)
x (Grams of pollutant/hp-hr) x (Unit conversion factor)
= Tons of pollutant/year

For all types of non-tractor farm equipment the equation is:

(Equipment population in AQCR) x (Avg hours of use/year)
x (Avg engine hp) x (Avg load factor) x (Grams of pollutant/hp-hr)
x (Unit conversion factor) = Tons of pollutant/year

Table 5 lists the emissions summary for each type of farm equipment estimated for the North Central Iowa AQCR in 1973. As discussed in a preceding section, emissions from self-propelled combines include their estimated hours of AQCR operation as rentals.

TABLE 5

EMISSIONS FROM FARM EQUIPMENT IN THE NORTH CENTRAL IOWA AQCR, 1973

	Tons per Year			
	HC	CO	NO_x	SO_x
Tractors, Gasoline	1,110	44,500	2,080	71
Diesel	1,050	1,700	5,500	484
Total Tractors	2,160	46,200	7,580	555
Combines, S.P., Gas	259	7,700	194	10
S.P., Dsl.	11	21	54	5
Pull, Gas	6	175	4	*
Windrowers, S.P., Gas	73	2,190	55	3
S.P. Dsl	3	6	16	2
Balers, Pull & S.P., Gas	11	330	8	*
Forage Harvesters, S.P., Dsl	3	6	15	1
Miscellaneous, Gas	79	2,360	60	3
Dsl	2	4	11	1
Total, Non-Tractor Equipment	447	12,800	417	25
Total Emissions	2,610	59,000	8,000	580

Notation: S.P. = Self-propelled Unit

* Indicates less than 1.0 ton per year

Projected Growth Analysis

The future of the U.S. tractor population is considered first. This category is unique in that the total population is declining. The ratio of gasoline power to diesel power is also rapidly changing, as is the average engine horsepower. These parameters must be accounted for in any growth analysis. (The term growth is used even though, in this case, it is a negative growth.) The following analysis predicts tractor growth rates to 1990. Average usage, emission and load factors are assumed to remain relatively constant over that period.

The U.S. Department of Agriculture recently completed a study on the energy needs of the food industry [1]. Since farm machines are major fuel consumers (they consumed 70% of all liquid petroleum fuel used on farms in 1970), the USDA projected their needs into 1980. A decline of 20% between 1970 and 1980 is predicted for the farm tractor population. During that time the percentage of diesel powered tractors is estimated to grow from 20% to 57% of the population. The USDA report does not go beyond 1980, but it is apparent that the number of tractors will not decline indefinitely. The cause of the decline is that as farms become larger, they have greater capability for more efficient tractor use. They purchase fewer but more powerful tractors. The amount of land being farmed shows no signs of being reduced, however, as food production must meet the demands of increasing national and global human population. Thus, it follows that the tractor population will eventually stabilize at a constant level. This level is assumed to be approximately 3.7 million units: USDA's projected 1980 population. In other words, the U.S. tractor population will experience a negative growth rate through 1980, then remain nearly constant at least for the next decade.

The analysis becomes even more complex when the gasoline/diesel distribution is considered. There is no indication that the trend toward more diesel tractors will change. In 1974 80% of tractor purchases were diesel. The higher initial purchase price of diesels is offset by their greater combustion efficiency, longer service life, and less expensive fuel. So, even though the total number of tractors is assumed to stabilize by 1980, the percentage that are diesel powered is assumed to continue a steady increase. Figure 1 graphically illustrates the predicted U.S. tractor population through 1990, and the shift from the present gasoline domination to a predominantly diesel composition. The curves of gasoline and diesel tractors are drawn using the 1973 percentages derived in this analysis and using USDA figures through 1980. They are extended to 1990 in such a way that their sum equals a constant 3.7 million. The rates calculated from Figure 1 show that the gasoline tractor population will decrease approximately -7.0% per year through 1980, and thereafter at a rate of -3.5% a year. The diesel tractor population, on the other hand, is projected to grow at a rate of about 4.0% per year through 1980, and thereafter at 2.0% per year.

The next step is to project the growth rate of average tractor PTO horsepower. For the past 50 years average tractor power has

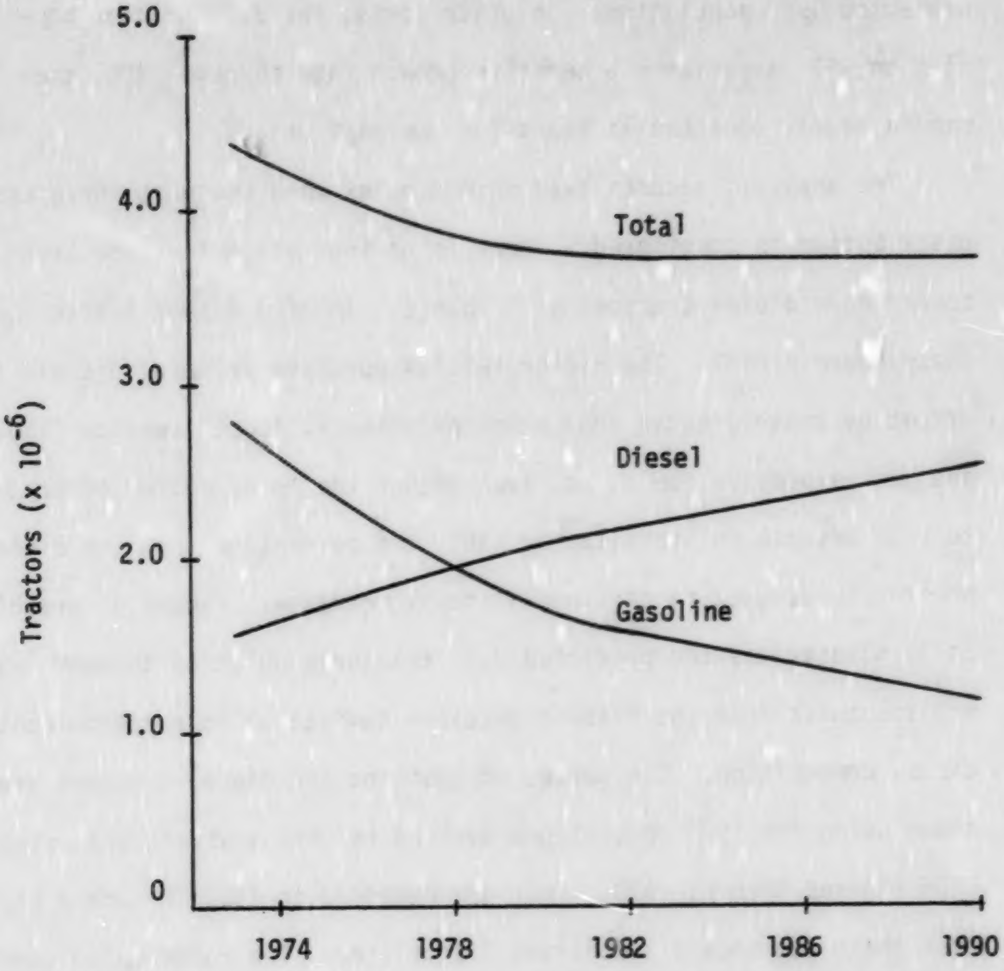


Fig. 1. Projected farm tractor population in the United States

increased, with diesel tractor horsepower increasing more rapidly than gasoline horsepower. Over the years 1963 to 1973 average tractor PTO hp increased at an average rate of 3.3% per year. Future growth rates are projected as 3.0% per year for average diesel tractor PTO hp, and 1.5% per year for average gasoline tractor PTO hp.

Now growth rates for farm equipment other than tractors may be considered. The emissions summary for the North Central Iowa AQCR shows very low emissions from pull type combines, pickup balers, and forage harvesters. Therefore, it is reasonable to discontinue their separate listings and include them in the miscellaneous category. The reasoning is that any effort expended on these implement types would be better put to use on the more populous implements: self-propelled combines and windrowers.

Compared to tractors, very little information is available on growth rates of other types of farm equipment. The average horsepower is, therefore, held constant at 1973 levels; undoubtedly, a conservative act.

The U.S. Department of Agriculture predicts that by 1980 there will be 534,000 self-propelled combines in the U.S., 30% of them diesel [1]. This shows a tremendous growth by diesel units which accounted for only 15% of the 1973 population. Furthermore, the USDA estimates 90% of combine sales in 1980 will be diesel. Combines have become the most widely used harvesting implement because of their efficiency and versatility. Taking the USDA projections into account, the growth rate of self-propelled diesel combines is estimated to be 12.0% per year through 1990. Gasoline units, following the tractor trend, are decreasing in absolute numbers. The growth rate of gasoline combines is projected to be -1.5% per year through 1990.

A similar trend can be projected for self-propelled windrowers. Since no yearly windrower population data are available, sales data are used to estimate the following growth rates. The U.S. self-propelled diesel windrower population will increase at a rate of 6.0% per year through 1990, and the gasoline windrower population at a rate of -1.0% per year.

The only source of information concerning miscellaneous engines used in farm equipment is from a trade magazine [5]. The annual population is apparently declining as the total number of U.S. farms also declines. However, as farms become larger, implements become more specialized and an independent engine is still the most efficent power source (at least on a short term basis). Thus, it is predicted that the population of miscellaneous internal combustion engines will grow at a slow but steady pace at least until 1990. In particular, engines used in cultivation rather than harvesting, such as irrigation pumps, and sprayers for fertilizer, herbicides, and pesticides will become more popular as larger areas of marginally arable land need to be planted. Since most of these engines are small, they are assumed to remain 90% gasoline powered. The projected growth rate of miscellaneous farm engines is 2.0% per year for both gasoline and diesel units.

A summary of the projected growth rates for each type of farm equipment is listed in Table 6 . All available data indicate that the growth rates derived for U.S. farm equipment populations are applicable to Iowa and, specifically, its North Central AQCR. There is no reason to predict that Iowa will relinquish its position as leader in terms of number of tractors owned, nor that its future farm growth will differ from that which has been predicted for the total U.S.

TABLE 6

PROJECTED FARM EQUIPMENT GROWTH RATES

	Percent Increase Per Year	
	1973-1980	1981-1990
Tractor Population, Gasoline	-7.0	-3.5
Diesel	4.0	2.0
	1973-1990	
Tractor PTO hp, Gasoline	1.5	
Diesel	3.0	
S.P. Combine Population, Gasoline	-1.5	
Diesel	12.0	
S.P. Windrower Population, Gasoline	-1.0	
Diesel	6.0	
Miscellaneous Engine Population, Gasoline and Diesel	2.0	

Predictive Computer Program

The computer program which can be used to estimate annual emissions from farm equipment in any Air Quality Control Region is listed in Appendix 1. Emissions from the following types of equipment may be predicted for any year between 1973 and 1990.

1. Tractors
2. Self-propelled combines
3. Self-propelled windrowers
4. Miscellaneous farm engines

In the program fixed values are assigned to parameters which are considered to remain constant through the years. These include usage rates, emission factors, load factors, and the average size of non-tractor engines. The input parameters are the projected annual growth rates of 1) the tractor population in the AQCR through 1980, and from 1981 to 1990, 2) the average tractor PTO horsepower, 3) the self-propelled combine population, 4) the self-propelled windrower population, and 5) the miscellaneous farm engine population. Separate growth rates may be entered for gasoline and diesel populations.

Indicator parameters are user-entered data from which the base year (1973) AQCR farm equipment populations are derived. They are the populations of each equipment type from the 1969 Census of Agriculture. The AQCR populations are acquired by summing the appropriate county data. The program updates the data to 1973 levels by the following routine.

$$\frac{\text{Equipment in AQCR, 1973}}{\text{Equipment in AQCR, 1969}} = \frac{\text{Equipment in U.S., 1973}}{\text{Equipment in U.S., 1969}}$$

Windrower populations are updated by the ratio of national windrower sales of 1969 and 1973. There are, of course, no data on the number of miscellaneous farm engines in the Census of Agriculture. A farm equipment trade magazine estimates their 1973 national population to be 1,160,000 units [5]. Using this figure an AQCR population is estimated by the equation:

$$\frac{\text{Misc. engines in AQCR, 1973}}{\text{Misc. engines in U.S., 1973}} = \frac{\text{No. of farms in AQCR, 1969}}{\text{No. of farms in U.S., 1969}}$$

The number of farms by county are listed in the 1969 Census of Agriculture. The total number in the U.S. at that time was 2,730,250 farms.

Starting with the 1973 AQCR implement populations the computer program calculates the number which are gasoline and diesel powered and, if necessary, the number which are powered by an independent engine. These factors have been discussed in a preceding section.

To summarize, the input data and indicator parameters which must be supplied by the user are:

1. AQCR 1969 equipment populations of tractors, self-propelled combines and total windrowers (the program will estimate the number that are self-propelled)
2. The number of farms in the AQCR in 1969
3. The projected growth rate of each implement type in percent increase per year (a negative growth rate may be entered)

A complete description of the required format for the input data is included in Appendix 1.

Figure 2 is a sample of the printed computer output. Estimated 1973 farm equipment population is shown for the North Central Iowa AQCR, and the resulting exhaust mass emissions. Note that there are slight differences between these figures and those in Table 5. This is partly because the computer program uses national data in the calculations, and the emissions in Table 5 are derived using more specific Iowa data. Furthermore, the computer program does not include any emissions that may be a result of the operation of rented or leased farm equipment.

Figures 3 to 6 graphically illustrate the emission trends of HC, CO, NO_x, and SO_x emissions, respectively, in the North Central Iowa Air Quality Control Region through 1990. The projected growth rates reflected in these graphs are those listed in Table 6.

Comparison with Other Air Pollution Sources

The 1976 emissions inventory for the North Central Iowa Air Quality Control Region is shown in Table 7. Emissions from farm equipment are those predicted by the computer program using the growth rates developed in the preceding section. Other source emissions are from the Environmental Protection Agency's National Emissions Data System as of May 1, 1976 [17].

```
YEAR    1973

                                   FARM EQUIPMENT POPULATION

                            GASOLINE       DIESEL        TOTAL

TRACTORS                     31825.        17824.       49649.
  AVG PTO HP                  36.0          70.3
COMBINES, SELF PROP.          4747.          838.        5584.
WINDROWERS, SELF PROP.        1954.          345.        2299.
MISCELLANEOUS EQUIP           8104.          900.        9004.


                                       EXHAUST EMISSIONS  (TONS PER YEAR)

                               HC            CO            NOX          SOX

TRACTORS - GASOLINE           1092.        43908.        2046.          70.
TRACTORS - DIESEL             1032.         1673.        5427.         477.
  TOTAL, TRACTORS             2124.        45581.        7473.         548.

COMBINES - GASOLINE            214.         6385.         161.           8.
COMBINES - DIESEL                9.           18.          45.           5.
WINDROWERS - GASOLINE           74.         2191.          55.           3.
WINDROWERS - DIESEL              3.            6.          16.           2.
MISCELLANEOUS - GASOLINE        95.         2826.          71.           4.
MISCELLANEOUS - DIESEL           3.            5.          13.           1.
  TOTAL, NON TRACTOR EQUIP     398.        11431.         361.          22.

TOTAL EMISSIONS               2522.        57012.        7834.         570.
```

Fig. 2. Sample output of farm equipment computer program

FIGURE 3

PROJECTED FARM EQUIPMENT EMISSIONS : HC

NORTH CENTRAL IOWA AQCR

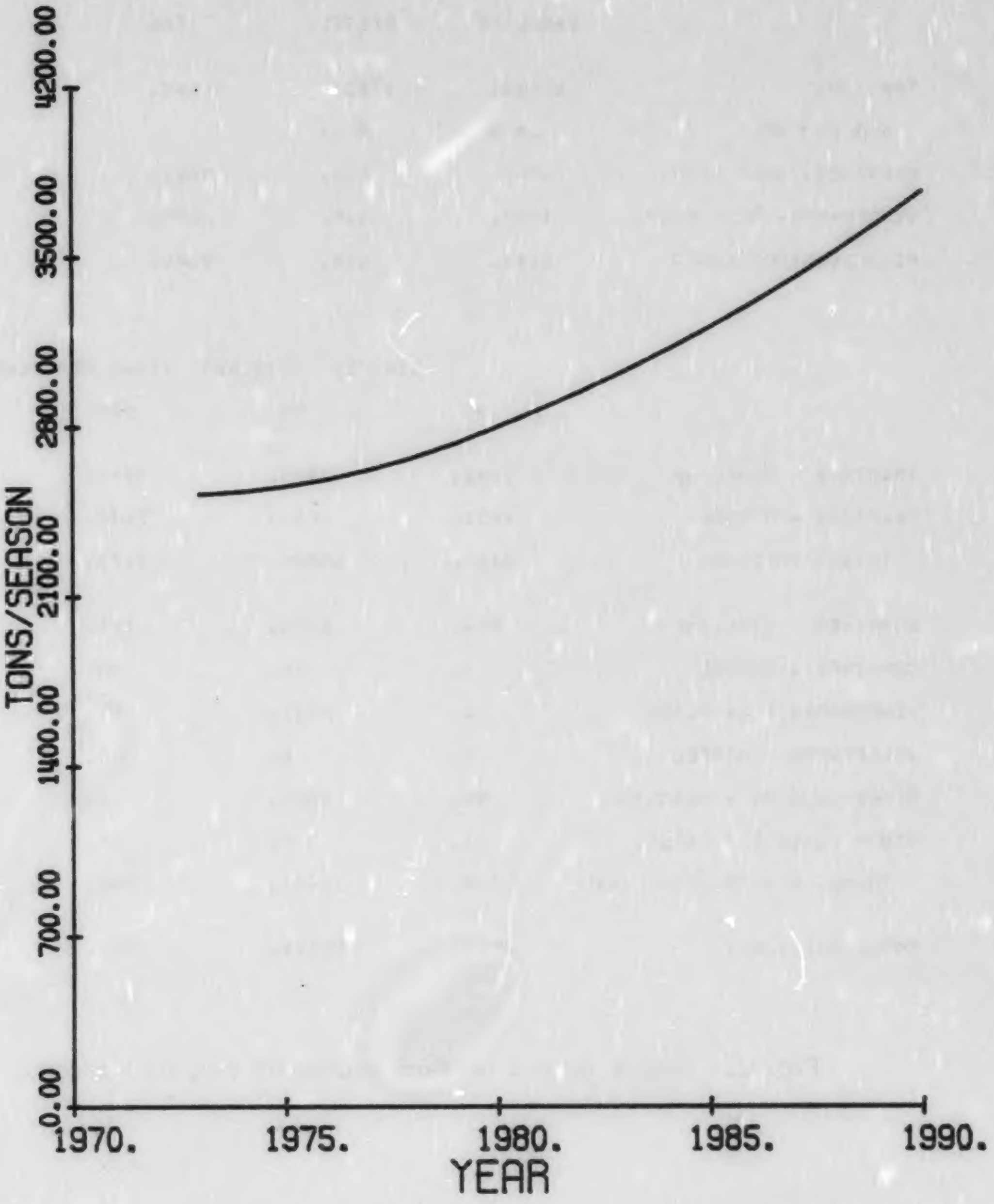


FIGURE 4

PROJECTED FARM EQUIPMENT EMISSIONS : CO

NORTH CENTRAL IOWA AQCR

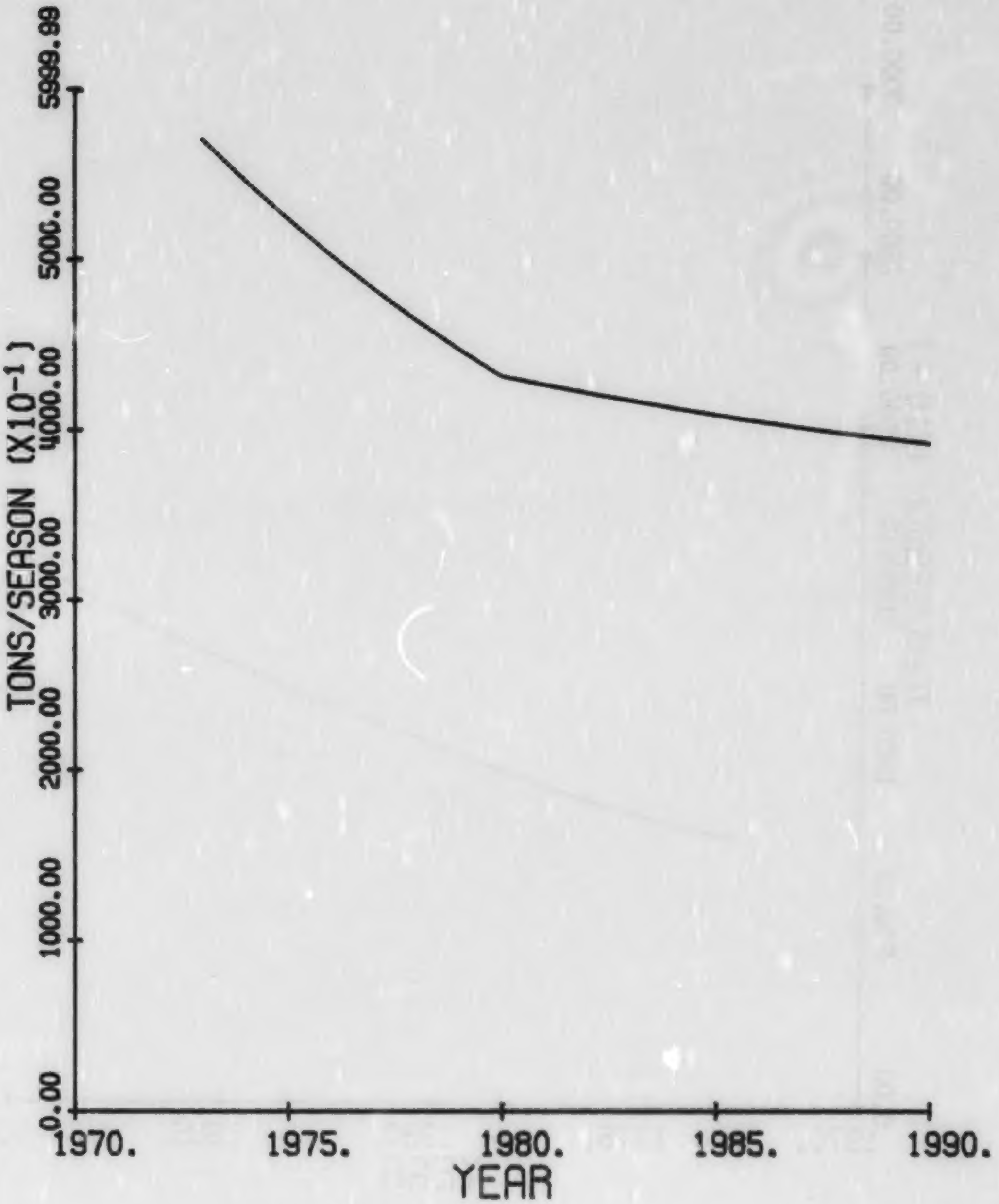


FIGURE 5

PROJECTED FARM EQUIPMENT EMISSIONS : NOX

NORTH CENTRAL IOWA AQCR

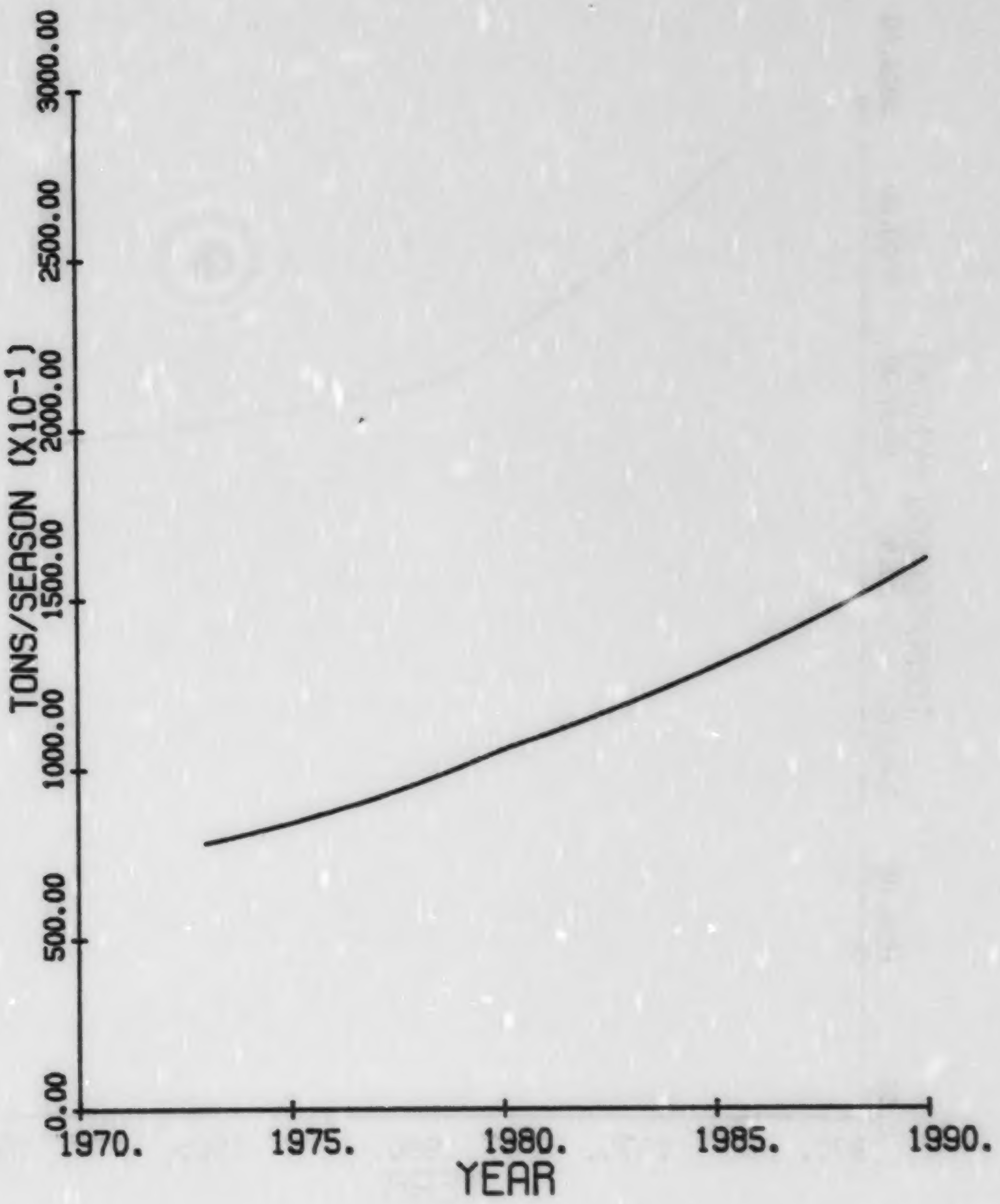


FIGURE 6

PROJECTED FARM EQUIPMENT EMISSIONS : SOX

NORTH CENTRAL IOWA AQCR

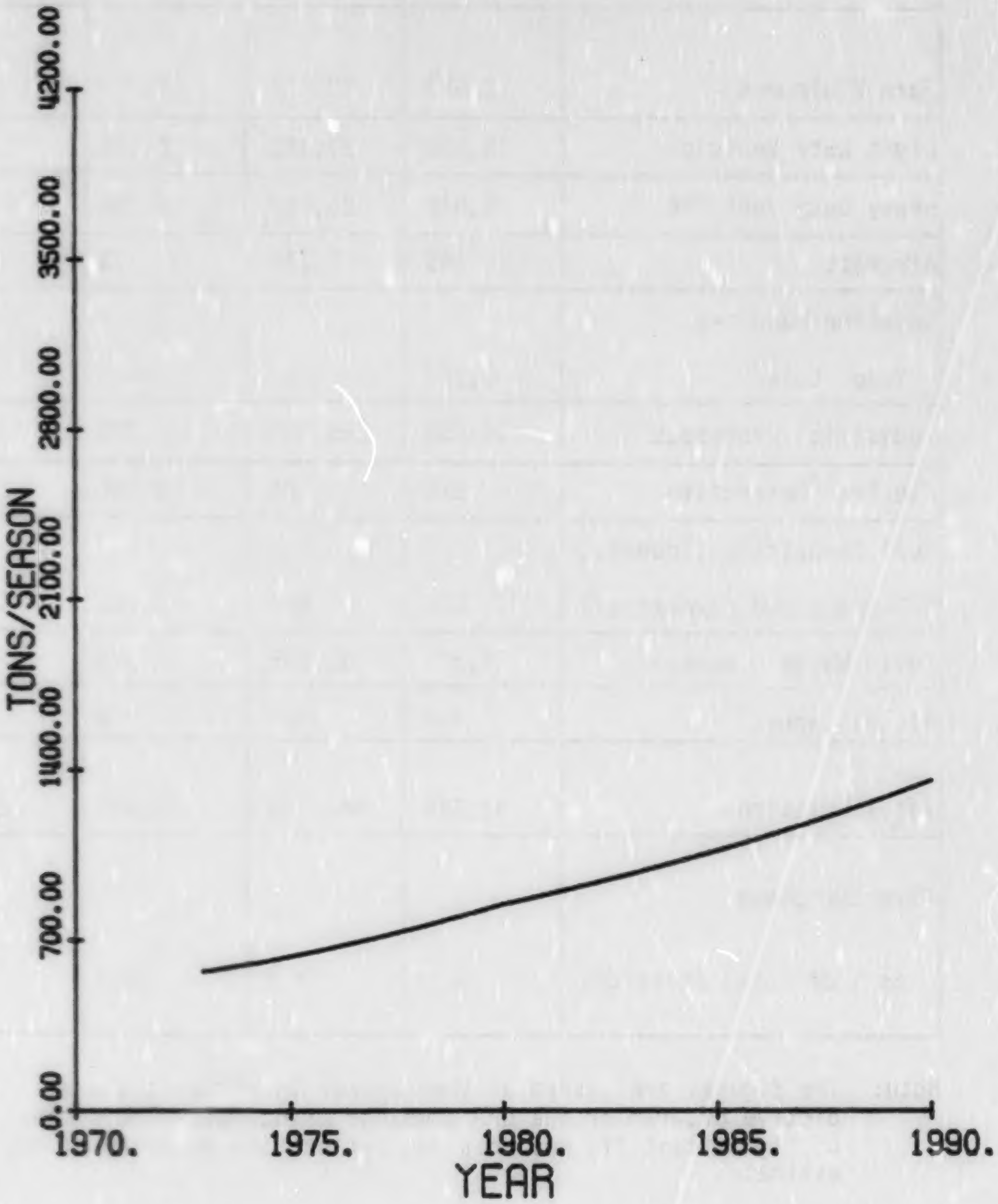


TABLE 7

EMISSIONS INVENTORY FOR THE NORTH CENTRAL IOWA AQCR, 1976

Source	Tons per Year			
	HC	CO	NO_x	SO_x
Farm Equipment	2,583	50,252	8,770	670
Light Duty Vehicles	15,399	87,153	10,616	316
Heavy Duty Vehicles	5,013	26,981	4,785	373
Aircraft	245	1,218	78	13
Gasoline Handling Evap. Loss	2,267	--	--	--
Industrial Processes	11,738	265,313	1,393	14,352
Electric Generation	246	93	3,152	2,558
Fuel Combustion (Indust., Resid., and Commercial)	253	665	3,662	2,047
Solid Waste Disposal	4,341	12,205	979	235
Miscellaneous	494	220	8	--
Total Emissions	42,579	444,100	33,443	20,564
Farm Equipment as % of Total Emissions	6.1	11.3	26.2	3.3

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

All the figures are estimates, but it is evident that farm equipment may have a significant impact on the total air pollution burden of this rural area. On a mass basis carbon monoxide is emitted in the greatest quantities. Farm equipment is responsible for about 11% of the total, mostly as a result of gasoline powered tractor operation. However, as the trend to diesel power continues in agriculture, the amount of CO emissions will decrease. This is clearly illustrated in Figure 4.

Of more importance are emissions of oxides of nitrogen. At the present time farm equipment contributes about one-fourth of the annual NO_x emissions in this region, ranking second only to light duty vehicles (automobiles). The high compression ratio of diesel engines produces higher combustion temperatures than those in spark-ignited gasoline engines. This results in greater NO_x emissions. As Figure 5 indicates, the shift to diesel powered equipment is predicted to double NO_x emissions from farm equipment by 1990. Over this same period emission regulations on light duty vehicles can be expected to greatly reduce the release of NO_x from this source.

Emissions of hydrocarbons and sulfur oxides from farm equipment are less significant, being about 6% and 3%, respectively, of the region's 1976 emissions. But these pollutants also will be increasing with time and, in the case of hydrocarbons, a reduction in emissions from automobiles will mean a definite increase in the relative impact of farm equipment HC emissions.

In conclusion, the analysis of this particular Air Quality Control Region shows that farm equipment can be a significant source of gaseous pollutants typically emitted in the exhaust of internal combustion engines. In other regions of extensive agricultural activity, however, the contribution may be much different. The accompanying computer program has been developed to allow a reasonably quick and accurate estimation of farm equipment emissions in any Air Quality Control Region.

It is important to understand that even though farm equipment may account for a large percentage of a region's total emissions, annual emission rates in most farming communities are still much lower than those of highly industrialized urban areas. But, if it can be assumed that a national goal is to prevent the deterioration of air quality in any part of the country, then emissions from farm equipment deserve equitable scrutiny.

PART 2

MERCHANT VESSELS

Ships provide a vital but often unnoticed role in world-wide distribution of goods. From mammoth ocean-going tankers to durable Great Lakes ore carriers to high-powered river towboats, more freight is being transported on U.S. waterways today than at any time in the past thirty years. Most ships are powered either by diesel engines or by steam turbines. The combustion of fuel, which can range from light diesel fuel down to residual oil, results in the emission of gaseous pollutants. The large size of vessel powerplants, and the fact that their use can be concentrated in limited areas (harbors or rivers), warrants a study of their relative impact on air pollution.

This Part analyzes the mass emission rates of merchant vessels in a selected Air Quality Control Region, and presents a computer program which can be used to predict annual vessel emissions in any AQCR which has ship traffic. The term merchant vessel refers to any self-propelled vessel engaged in commerce. Military and recreational vessles are, therefore, excluded. The category is divided into three vessel classifications: 1) tugboats and towboats, 2) motorships, and 3) steamships. Motorships are propelled by diesel engines, while steamships burn fuel in boilers which in turn provide steam either to turbines or reciprocating steam engines. Tugs and towboats are essentially all diesel powered.

Powerplants used in vessels vary extensively in design, and very limited study has been done on their exhaust emissions. This analysis is limited to the estimation of emissions from the main propulsion units while the vessel is underway. Emissions from auxilary engines is not included. Most vessels have auxilary engines or boilers for electrical generation, domestic requirements, cargo handling, emergency pumping, and numerous other shipboard activities. Information concerning the number of these engines used on vessels, their types, size, operating times and conditions is not available. Furthermore, this same machinery often provides power while the ship is docked. It is decided that rather than attempt a very rough estimate of emissions from auxilary equipment, effort would be better expended on the main propulsion units. Their greater size would seem to indicate that their emissions are much more significant.

Estimation of Emissions in a Selected AQCR

The nation's busiest waterways are those of New York harbor. Nearly one in every five ships which call at ports in the continental United States does so at the Port of New York. This is almost twice the traffic of the second busiest port, New Orleans [1]. It follows that any research on air pollution by vessels should begin in the metropolitan New York area. The New Jersey-New York-Connecticut Interstate Air Quality Control Region includes all of New York City and Long Island, northeastern New Jersey, and the southwest corner of Connecticut. It encompasses the following counties.

In the State of New Jersey:

Bergen
Essex
Hudson
Middlesex
Monmouth
Morris
Passaic
Somerset
Union

In the State of New York:

Bronx
Kings
Nassau
New York
Queens
Richmond
Rockland
Suffolk
Westchester

In the State of Connecticut:

Fairfield

The 1970 population of the AQCR was 17.35 million, in an area of 4,985 square miles. Vessel traffic in all of the region's navigable waterways are included in the analysis. The most recent information available is for the 1973 calendar year, so this is chosen as the base year. All major waterways are open the entire year so mass emissions of HC, CO, NO_x, and SO_x are estimated on a yearly basis.

The parameters needed to perform this analysis are:

1. Hours of vessel operation in the AQCR
2. Average engine size (horsepower)
3. Average engine load factor
4. Emission factors (grams of pollutant per horsepower-hour)

The sections which follow derive these parameters for each of the three vessel classifications.

Hours of Operation in the AQCR

Complete vessel traffic records are kept by the U.S. Army Corps of Engineers for every navigable waterway in the United States. Yearly statistics are compiled in Waterborne Commerce of the United States [2]. For each waterway the total vessel movements (trips), both inbound and outbound, are listed for various types of vessels. The types which are of interest for an air pollution analysis are self-propelled vessels of three classifications: 1) tugboats and towboats, 2) dry cargo and passenger ships, and 3) tankers. For this study the latter two classifications are combined and are eventually referred to as motorships or steamships depending on their power source.

A total of 48 waterways in the AQCR recorded vessel movements in 1973. In 13 of these the movements were relatively light and they were subsequently deleted from the analysis. The majority of movements took place in Upper and Lower New York Bays, the East River, and the Hudson River Channel. The length of each waterway is also given in Waterborne Commerce of the United States. By multiplying the length, in miles, times the total movements of self-propelled vessels (inbound plus outbound), the vessel-miles travelled in each waterway in 1973 is calculated. Obviously, not every vessel traversed the entire length of a waterway on each trip. This is particularly true on such waterways as the Hudson River Channel and the East River. Most of the marine terminal facilities are located on the lower portions of these rivers. In such cases the waterway length is re-evaluated to indicate the average distance of a vessel trip on that waterway. This is based primarily on location of terminals, or, in the case of ferryboats, the actual distance travelled in a scheduled trip. The total miles of vessel travel on waterways is shown in Table 8.

TABLE 8

VESSEL TRAFFIC ON THE WATERWAYS OF THE
NEW JERSEY-NEW YORK-CONNECTICUT AQCR, 1973

Vessel Type	Total Vessel-miles
Tugs and Towboats	4,042,000
Tanker, Cargo, and Passenger Ships	3,139,000

It should be noted that vessel-miles are calculated using straight line lengths of channels. Maneuvering, such as arriving or departing from docks, adds extra distance to the trip. This applies most strongly to tugs which are used extensively to maneuver large ships in the harbor. Thus, the above figures are probably conservative.

The miles of vessel travel is translated into hours by dividing by the vessel speed. The speed at which a vessel moves depends not only on the engine and hull capabilities but also on the type of waterway, the amount of other vessel traffic, currents, etc. United States Coast Guard personnel stationed on Governors Island state that speeds in the waters of New York harbor range from 3 to 15 knots [3]. The higher speeds are attained in the open waters of the Lower Entrance Channels, or the Upper Bay, by ocean-going deep draft ships and by ferries. The percentage of harbor traffic caused by ocean-going vessels is relatively small. Less than 15% of the total vessel-miles is by ships with drafts greater than 18 feet. Most traffic is by intra-harbor vessels. Some rough estimates of typical speed as cited by the Coast Guard are: for a light tug with no tow, 10.5 knots; tug with tow, 3 to 8 knots; intra-harbor tanker, 6 to 10 knots. The only regulations on speed occur in the harbor anchorage areas where the maximum permissible speed is 6 knots. In the narrower waterways, however, pilots often proceed at speeds even less than 6 knots to minimize wakes. These are underway speeds though. They do not account for time spent achieving the speed from a stop (leaving dock), or in slowing down (approaching dock). Taking these factors into consideration a speed of 7 knots is assumed to be a reasonable average. This is equal to 8 miles per hour and is used for all vessel types in all waterways of New York harbor.

The next step is to determine the relative populations of vessels by type of propulsion. Tugboats are all diesel powered, but tanker, cargo, and passenger ships may have diesel or steam power. Statistics on the 1973 world's trading fleet show that by population 89% are motorships, 11% are steamships [4]. Steamships account for 64% of the gross tonnage, indicating that very large vessels are most often powered by steam turbines. Since the data used to arrive at miles of vessel travel are based on vessel movements, they can be assumed to reflect the vessel population in terms of engine type. Thus, total hours of vessel operation in the AQCR can be calculated from the average speed and the population based percentages cited. Table 9 lists the total hours of 1973 vessel operation on the waterways of the AQCR.

TABLE 9

HOURS OF VESSEL OPERATION IN THE
NEW JERSEY-NEW YORK-CONNECTICUT AQCR, 1973

Vessel Type	Total Vessel-hours
Tugs and Towboats	505,200
Motorships	349,200
Steamships	43,200

Average Engine Size

Since exhaust emissions are assumed to be linearly proportional to engine size, it is necessary to determine the average horsepower of each vessel type. The Record of the American Bureau of Shipping-1973 Ship Register lists extensive engine specifications for every U.S. registered vessel [5]. A random sampling of vessels resulted in an average rated horsepower of diesel engines used in tugs and towboats of 1,800 hp. Some newer boats, particularly river towboats, have up to 10,000 hp for pushing tows nearly a quarter of a mile long.

As would be expected engines in motorships have a very large range of from less than 1,000 hp to almost 30,000 hp. The average is 6,400 hp. As in most vessels motorships have multiple main engines, and the figures listed here are the total maximum horsepower of all the engines which can be used for propulsion.

The largest ocean-going ships are generally steam powered. Reciprocating steam engines are still used, but turbines are much more popular because of their greater power to weight ratio [6]. The major advantage steam has over diesel is that boilers can burn viscous, Bunker C fuel oil, as well as distillates. Steam turbine power is defined in terms of shaft horsepower, and the average size of U.S. steamships is determined to be about 13,800 shp.

Average Engine Load Factor

Emissions are dependent on engine loading, and estimating an average load factor for a category as diverse as merchant vessels is difficult. In the case of tugs a study on Mississippi River towboats states that these vessels are using 85% of full power when travelling upstream and 50% while going downstream [7]. But river towboats operate under fairly constant speed and load conditions, whereas harbor tugs perform numerous tasks and subsequently varying loads [8]. Without sufficient information from which to accurately derive an average load factor, a duty cycle which equally weights the time spent at five engine load points is chosen to represent the typical operation of a tug in New York harbor. This estimated duty cycle, listed in Table 10 , represents a load factor of 0.52.

The motorship classification is even more diverse than tugboats. Measurements on U.S. Coast Guard cutters illustrate this fact. At cruise conditions some engines were at 50% power while others operated at nearly full power [9]. Of course, in most harbors ships would never be at cruising speeds. New York harbor is very large, however, with areas of "open" water, such as the Upper and Lower Bays. It is probably safe to assume that vessels which always remain in the harbor waterways (ferries, service boats, etc.) operate near full power. Larger tankers and cargo ships, especially those which need tug assistance, use less power to run at harbor speeds. Table 10 lists the estimated duty cycle for motorships operating in New York harbor. It differs from the tug duty cycle in weighting mid-range engine loads more heavily. The resultant average load factor is 0.45.

Since steamships are usually very large vessels, their power utilization in a restricted area would seem to be low. A steam turbine has peak efficiency near full power. But this is an external combustion engine, and the critical factor is the boiler fuel consumption rate, since that is the source of emissions. The average load factor is estimated to be 0.33, but this is not based on any actual measurements.

Emission Factors

The amount of exhaust gases emitted from vessel powerplants, either diesel or steam, is a function of the engine or boiler design, its age, the speed and load operating conditions, and fuel composition. Compared with most of the other categories in this project, for example, locomotives and farm equipment, the variability of engines used in ships is much greater. Many are very old; many are of foreign manufacture. The emission factors computed here are derived from extremely limited emission tests on a few engines which have application in vessel propulsion. They are representative of emissions from vessels using those particular engines, but they cannot be assumed to accurately represent an average of the total vessel fleet. Their primary purpose is to serve as an indication of the need for more extensive characterization of vessel emissions.

TABLE 10

ESTIMATED VESSEL DUTY CYCLES FOR HARBOR OPERATION

	Fraction of Time in Mode	
Percent of Full Power	Tugboat	Motorship
0 (idle)	0.20	0.15
30	0.20	0.30
50	0.20	0.30
80	0.20	0.20
100	0.20	0.05

Turning first to emission factors of diesel engines, there have been two recent works published. One analyzes stack emissions from Coast Guard cutters [9]. Over fifty diesel engines, both main and auxiliary, were tested under typical speed regimes, usually idle, one-third ahead, and full ahead. The results are given as fuel specific emissions: pounds of pollutant per 1,000 pounds of fuel. Other emission tests were performed by Southwest Research Instutute for the U.S.

Environmental Protection Agency [10]. The actual tests were run on three railroad locomotive engines: 1,000 hp and 3,000 hp 2-stroke engines manufactured by Electro-Motive Division of General Motors Corp., and a 3,300 hp General Electric 4-stroke diesel. Besides finding use in locomotives these engines, particularly the EMD's, are widely used as main engines in tugboats as well as vessels in the motorship classification. Brake and fuel specific emissions were measured at a number of engine speed and load conditions.

The following analysis of diesel engine emission factors utilizes data from the SWRI tests. They are considered more appropriate than the Coast Guard data because better information is available on the operation of vessel engines from a load (horsepower) standpoint than on a fuel consumption basis. Thus, brake specific emission factors are desirable. Furthermore, the SWRI procedures incorporate a wider range of engine operating points. It must also be remembered that even though some motorships are of much greater horsepower than the engines tested by SWRI, they are often simply a number of the smaller engines operating in combination.

Emissions from the three test engines are weighted according to the duty cycles estimated for tugs and motorships in the preceding section. Emissions are taken as near as possible to the five load points (idle, 30,50,80, and 100% of full power). Since only three engines are being used, emissions from each are equally weighted to arrive at composite emission factors. Table 11 lists the HC, CO, and NO_x composite emission factors as weighted by the tug and motorship duty cycles.

The only source of emission data from a typical steamship boiler is the Coast Guard study [9]. Unfortunately, only one steam turbine cutter was tested. Fuel specific emissions from two Babcock and Wilcox oil-fired boilers were measured at idle, cruise, and full power. Since the amount of data are so minimal, it is meaningless to consider a weighted average according to a duty cycle. So an equal weighting is assigned to each of the three mode points for CO and NO_x emissions. Hydrocarbons were not measured at idle, so it is equally weighted between cruise and full modes. Fuel specific emissions are converted to brake specific emissions by using the specific fuel consumption (lb fuel/hp-hr). The fuel rate for most marine boilers is between 0.35 and 0.65 lb/hp-hr [11,12]. Boiler design is highly variable and is continually evolving. The lower figure represents the latest technology of a reheat boiler. But many vessels in the merchant fleet have older, less efficient machinery. Also, these fuel rates are for boilers with constant fuel flow in underway operation. No data exists on typical fuel rates experienced at reduced draft conditions which is much less efficient. Even though a steamship at harbor speeds probably has a greater specific fuel rate, the average specific fuel consumption for oil-fired marine boilers is estimated to be 0.52 lb fuel/shp-hr (236. g fuel/shp-hr). Using this figure the steamship emission factors are calculated as shown in Table 11 .

Up until now SO_x emissions have not been mentioned. Estimations of these emission factors are obtained in a different manner. The analysis is based on the assumption that all sulfur in the fuel is oxidized in the combustion process and is emitted as SO_2. Emissions are thus dependent on the rate of fuel consumption and the fuel's sulfur content. The average specific fuel consumption of steamships has already been estimated. Fuel rates for tugs and motorships are derived from SWRI test data. At each test mode SWRI recorded mass fuel rate (lb/hr) and gross horsepower generated. This gives specific fuel consumption at each mode. By weighting the modes according to the appropriate duty cycle, the average specific fuel consumption for engines used in tugs is calculated to be 1.29 lb/hp-hr (585. g fuel/hp-hr) and for motorships it is 1.06 lb/hp-hr (481. g fuel/hp-hr). It is evident that these rates are greater than that estimated for a steamship. This is probably unreasonable, and more confidence should be given to the calculated diesel emission factors than those for marine boilers.

The sulfur content of marine fuels must now be determined. This is a highly variable element in petroleum, but reasonable estimates are 0.5% sulfur by weight in diesel fuel and 1.0% sulfur in residual oil [9,11]. Emission factors for SO_x can now be calculated from the following equation. The results are listed in Table 11 .

$$\text{(g fuel/hp-hr)} \times \text{(g S/g fuel)} \times (2 \text{ g } SO_2/\text{g S})=$$
$$\text{Grams } SO_2/\text{ hp-hr}$$

TABLE 11

MERCHANT VESSEL EMISSION FACTORS

	Grams per Horsepower-hour			
	HC	CO	NO_x	SO_x
Tugs and Towboats	14.8	14.5	26.9	5.85
Motorships	11.6	12.9	22.5	4.81
Steamships	0.037	0.248	1.26	4.72

Base Year Emissions

The parameters which have been identified in the preceding sections are now used to estimate mass emissions of HC, CO, NO_x, and SO_x from merchant vessels. Emissions are calculated by the equation:

(Hours of vessel operation in AQCR) x (Avg engine hp)
x (Avg load factor) x (Grams of pollutant/hp-hr)
x (Unit conversion factor) = Tons of pollutant/year

The emissions for the three vessel classifications estimated to have resulted from their operation on the waterways of the New Jersey-New York-Connecticut Air Quality Control Region in 1973 are listed in Table 12 .

TABLE 12

EMISSIONS FROM MERCHANT VESSELS IN THE NEW JERSEY-NEW YORK-CONNECTICUT AQCR, 1973

	Tons per Year			
	HC	CO	NO_x	SO_x
Tugs and Towboats	7,710	7,560	14,000	3,050
Motorships	12,900	14,300	24,900	5,330
Steamships	8	54	272	1,020
Total Emissions	20,600	21,900	39,200	9,400

Projected Growth Analysis

The best source of data on vessel traffic in New York harbor is the annual Waterborne Commerce of the United States [2]. Listed are vessel movements and freight traffic in the port. Over the years 1963 to 1973 total tonnage of commerce handled by the port has increased steadily. There was a significant drop in 1974 as a result of the oil embargo [13]. However, there has not been a similar trend in regard to vessel movements. Vessel-miles show an erratic pattern of rises and falls over the same time period. This may be due in part to events such as strikes by dock workers which often last for weeks. But the major reason may be that the level of vessel traffic in New York harbor has reached a saturation level, and no significant increase will occur unless new terminal facilities are constructed. But most waterfront areas of Manhattan, Brooklyn, and New Jersey are fully developed, so it seems unlikely that there will be any major additions in the near future. The pattern seems to be not one of increasing vessel traffic, but rather that the size of cargo ships and tankers is increasing. There is also a growing fleet of container ships. In conclusion, all indications are that vessel traffic in the New Jersey New York-Connecticut AQCR is near its maximum level. Therefore, the best projection that can be made at this time is that vessel movements and the emissions they produce will remain comparable to the 1973 levels through 1990. This, of course, applies only to the Port of New York; other ports around the country may experience significant future changes.

Predictive Computer Program

The computer program which can be used to predict emissions from merchant vessels in any Air Quality Control Region in the country for any year between 1973 and 1990 is listed in Appendix 2. The category of merchant vessels is unique in that the type of ships operating in one port may be significantly different from those in another port. For example, vessels arriving at the Port of New York are quite unlike vessels arriving at the Port of St. Louis. For this reason the computer program contains subroutines for calculating emissions from three types of ports: ocean, lake, or inland. Examples of ocean ports are New York, New Orleans, and Los Angeles; lake ports are Chicago and Detroit; inland (or river) ports are St. Louis and Pittsburgh.

The input data which must be supplied by the user are as follows:

1. "JPORT" index: 1,2, or 3. If JPORT = 1, the user has designated the AQCR as an ocean port; 2 is a lake port; and 3 is an inland port.
2. Year of input data: must be either 1973 or 1974. (At the time the program was written the 1974 issue of Waterborne Commerce of the United States was being released. Thus, the user may input the required data from the 1973 or the 1974 issue.)
3. The number of waterways in the AQCR for which vessel movement data are entered.
4. The following inputs are needed for each waterway in the AQCR.
    a. Total movements (trips) in the waterway in both directions of self-propelled tankers, cargo, and passenger ships.
    b. Waterway length, in miles.
    c. Total movements in the waterway in both directions of self-propelled tugs and towboats.
5. Projected growth rate of vessel traffic (vessel-miles) in the AQCR through 1990, in percent increase per year.

A complete description of the required format for the input data is included in Appendix 2. All data on waterway lengths and vessel movements are found in Waterborne Commerce of the United States. Compiling the input data is straightforward, but may require some time if the AQCR contains many navigable waterways, as does the New Jersey-New York-Connecticut AQCR. But the data are very specific indicators of vessel traffic, so the time spent is justified by its accuracy.

Depending on the port type the program calculates the total miles of vessel travel in the AQCR, and apportions it accordingly among the following vessel types.

1. Tugs and towboats
2. Motorships
3. Steamships

If it is an inland port there is essentially no steamship traffic, so all tanker, cargo and passenger ships are assumed to be motorships (diesel). Vessel-miles are then converted to vessel-hours by dividing by average vessel speed. Table 13 lists the vessel parameters assumed to be typical for each type of port. As can be seen tugs and towboats are considered to be similar in all ports. But the average horsepower of motorships and steamships, and their relative population percentages, are variable. This information is based on a consensus of various sources [7,8,14-18].

Figure 7 is a sample of the printed output of the computer program. The estimated hours of vessel activity in the region is listed and the corresponding exhaust emissions. The listing is for merchant vessel traffic on the waterways of the New Jersey-New York-Connecticut AQCR in 1973. It should be noted that emissions from steamships are calculated under the assumption that their boilers are

TABLE 13

VESSEL PARAMETERS ACCORDING TO PORT TYPE

Type of Port	Avg Vessel Speed (MPH)	Tugs & towboats		Tankers, Cargo, & Passenger Ships					
				Motorships			Steamships		
		Avg HP	Avg LF	%	Avg HP	Avg LF	%	Avg HP	Avg LF
Ocean	8	1,800	0.52	89	6,400	0.45	11	13,800	0.33
Lake	10	1,800	0.52	33	4,000	0.45	67	4,000	0.45
Inland	8	1,800	0.52	100	1,500	0.45	0	--	--

Notation: HP=Horsepower

LF=Engine Load Factor

```
YEAR    1973

                         ESTIMATED VESSEL - HOURS :

TUG & TOWBOATS                                                    505343.
MOTORSHIPS (DIESEL POWERED CARGO, TANKER & PASSENGER SHIPS)       349233.
STEAMSHIPS (STEAM POWERED CARGO, TANKER & PASSENGER SHIPS)         43164.



                                 EXHAUST EMISSIONS  (TONS PER YEAR)

                           HC           CO          NOX          SOX

TUG & TOWBOATS           7717.        7560.       14025.        3051.
MOTORSHIPS              12861.       14302.       24945.        5331.
STEAMSHIPS                  8.          54.         272.        1022.

TOTAL EMISSIONS         20585.       21916.       39243.        9404.
```

Fig. 7. Sample output of merchant vessel computer program

residual oil-fired. There are still some steamers, particularly on the Great Lakes, that are coal-fired. This could significantly alter the emission rates, especially SO_x. At this time there have been no emission tests done on these vessels.

Since the projected growth rates of vessel traffic in the New Jersey-New York-Connecticut AQCR is zero, no computer generated plots are shown for this category.

Comparison with Other Air Pollution Sources

The 1976 emission inventory for the New Jersey-New York-Connecticut Air Quality Control Region is listed in Table 14.

Emissions from merchant vessels in 1976 are the same as were calculated for the base year of the analysis, 1973. As previously discussed, vessel traffic in this area is assumed to remain near the present levels. Other source emissions with one exception are from the National Emissions Data System as of May 1, 1976 [19]. The exception is the category of "industrial processes". The NEDS report lists hydrocarbon emissions from industrial processes in the region as over 15 million tons a year. Since the total HC emissions from all other sources is only one million tons, there is an obvious error in the data. Personnel at the U.S. Environmental Protection Agency's Regional Office in New York agree that annual emissions from industrial processes, while substantial, are not 15 million tons. Unfortunately, the reason for the error and the correct estimate could not be deter-

TABLE 14

EMISSIONS INVENTORY FOR THE NEW JERSEY-NEW YORK-CONNECTICUT AQCR, 1976

Source	Tons per Year			
	HC	CO	NO_x	SO_x
Merchant Vessels	20,585	21,916	39,243	9,404
Light Duty Vehicles	554,935	3,550,542	320,051	10,145
Heavy Duty Vehicles	74,510	429,366	67,488	6,040
Aircraft	7,852	19,225	5,392	588
Gasoline Handling Evap. Loss	66,637	--	--	--
Industrial Processes	108,187	71,993	10,395	49,448
Electric Generation	7,368	14,897	329,488	520,779
Fuel Combustion (Indust., Resid., and Commercial)	15,737	40,551	246,683	262,913
Solid Waste Disposal	42,357	127,526	8,300	4,650
Miscellaneous	183,860	--	--	--
Total Emissions	1,082,028	4,276,016	1,027,040	863,967
Merchant Vessels as % of Total Emissions	1.9	0.5	3.8	1.1

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

mined. So, lacking more precise information, data from the 1972 NEDS report are used to adjust the 1976 figures. The result is that industrial processes in the New Jersey-New York-Connecticut AQCR are estimated to produce just over 100,000 tons of HC per year.

When merchant vessel emissions are compared to the total air pollution burden of this region they do not appear very significant. Vessel powerplants emit NO_x in the greatest amounts, an estimated 4% of the total annual NO_x emissions. It is important to realize, however, that this region, even though it has the greatest amount of vessel traffic in the nation, also has the greatest human population and one of the heaviest concentrations of industrial activity. Merchant vessel emissions may have a higher degree of relative significance in other Air Quality Control Regions even though vessel movements are less than those on waterways of New York harbor. The computer program described in the previous section permits a quick and accurate means of estimating these emissions in any AQCR which has navigable waterways.

Another important point is the uncertainty of characterizing emissions from steam powered vessels. Emission factors were developed from very limited data. While steamship traffic in ocean ports such as New York is low compared to motorships, it may be a significant source of emissions on the Great Lakes where the majority of merchant vessels are steam powered. Therefore, it is recommended that more extensive emission tests be performed on marine boilers that are fueled by residual oil and by coal.

PART 3

LOCOMOTIVES

Railroads in the United States have gone through many critical periods. Starting with virtual control of the nation's land transportation in the early part of the century, their grip was broken by advances of the trucking industry. Now, partially as a result of an increased awareness of limited fossil fuel supplies, renewed interest is being given to railroads. In the past few years the federal government has subsidized two massive reorganizations-the National Railroad Passenger Corporation (Amtrak), and the Consolidated Rail Corporation (ConRail). The need to strengthen the railroad industry is evident. At the same time any adverse effects must be given equal consideration. This Part studies one negative aspect of railroad activity: the contribution to air pollution.

Essentially all locomotives today are powered by diesel engines. Locomotives are used in line haul (or road service) operation which is the long distance transporting of railroad cars, or in switchyard activities. The diesel engines can be either 2-stroke or 4-stroke cycle. The larger horsepower engines are usually turbocharged, and the smaller are Roots-blown. Since exhaust emissions may vary significantly according to the engine and air induction system, this analysis divides locomotive emissions into the following classifications.

1. Emissions during line haul operation from:
    a. 2-stroke Roots-blown engines
    b. 2-stroke turbocharged engines
    c. 4-stroke turbocharged engines
2. Emissions during switchyard activities from:
    a. 2-stroke Roots-blown engines
    b. 4-stroke Roots-blown engines

Estimation of Emissions in a Selected AQCR

Chicago is generally recognized as the center of railroading in this country. More railroads have their headquarters there than in any other city. Although track can be found in almost every county, the Chicago area has a very high concentration, particularly of yard track. Emissions from locomotives are, therefore, estimated for the Metropolitan Chicago Interstate Air Quality Control Region. The region consists of the following counties.

In Illinois:

Cook
DuPage
Grundy
Kane
Kankakee
Kendall
Lake
McHenry
Will

In Indiana:

Lake

Porter

The 1970 population of the AQCR was 7.76 million, in an area of 6,023 square miles. The base year for which emissions are estimated is 1973. The parameters needed to perform the analysis are:

1. Hours of locomotive operation in the AQCR
2. Average engine size (horsepower)
3. Average engine load factor
4. Emission factors (grams of pollutant per horsepower-hour)

The following sections discuss the methods used to derive each of the parameters.

Hours of Operation in the AQCR

Compared to the other categories covered in this report, discovering the amount of railroad operation on a regional level is most difficult. There is voluminous information on a national level, as well as for individual railroad companies. What is needed for an AQCR analysis, however, is the annual locomotive activity by county. The large railroads utilize computers to record locomotive and car movements, but there is no way to easily translate that information into regional traffic counts. Even the ConRail re-organization, which will eventually assess the operation of each of its branch lines, does not allow a systematic analysis of total county railroad traffic. In fact there is only one indicator of the amount of railroad activity in a county, and that is the amount of track mileage. It seems reasonable that a county with a great amount of track will sustain a proportional amount of railroad operation. This scheme has previously been suggested as a means of apportioning state railroad fuel usage to a county level. [1].

Therefore, realizing the limitations, locomotive activity in the Chicago AQCR is estimated by saying that the percentage of national railroad traffic that occurs in the region is equal to the percentage of national track mileage that is inside its boundaries. This assumes that every mile of track in the country carries an equal share of traffic. Obviously this is not true. Some lines are rarely used while others, such as most of those around Chicago, are main arteries. But lacking a more effective method this must be used. The resulting hours of locomotive operation in a major urban area are certainly less than the actual hours, whereas in a rural area with light traffic on its tracks the results would be greater than actual.

Having decided on a procedure for estimating total hours of locomotive activity in the Chicago AQCR in 1973, the first step is to determine the total miles of track in the region. Table 15 lists the railroad companies which operated in the AQCR in 1973. The Class I line haul railroads dominate road service in the U.S., in fact Class I companies own over 90% of all locomotives [2]. Operating statistics are available for each Class I railroad, so the miles of track each company operated on in the region are needed. A questionnaire was

TABLE 15

RAILROAD COMPANIES OPERATING IN THE CHICAGO AQCR IN 1973

Class I Line Haul Railroads

Atchison, Topeka & Santa Fe	ATSF	Elgin, Joliet & Eastern	EJE
Burlington Northern	BN	Erie Lackawanna	EL
Baltimore & Ohio	BO	Grand Trunk Western	GTW
Chesapeake & Ohio	CO	Illinois Central Gulf	ICG
Chicago & Eastern Illinois	CEI	Louisville & Nashville	LN
Chicago & North Western	CNW	Norfolk & Western	NW
Chicago, Milwaukee, St. Paul & Pacific	MILW	Penn Central	PC
Chicago, Rock Island & Pacific	CRIP	Soo Line	SOO

Class I Terminal and Switching Railroads

Baltimore & Ohio Chicago Terminal
Belt Railway of Chicago
Indiana Harbor Belt

Class II Terminal and Switching Railroads

Chicago Heights Terminal Transfer
Chicago & Illinois Midland
Chicago River & Indiana
Chicago Short Line
Chicago & Western Indiana
Chicago, West Pullman & Southern
Illinois Northern

mailed to each company requesting that they list, for each of the eleven counties, the miles of track operated on and classifying it as 1) running track, 2) way switching track, or 3) yard switching track. (Train switching, as opposed to yard switching, is performed en route, not in a yard. It is done by the line haul locomotive on way switching track.)

Fifteen questionnaires were mailed. One railroad, the Elgin, Joliet & Eastern, operates completely within the AQCR so its total operations are included. Eight were completed and returned, although two arrived too late to be used. For the companies that did not cooperate an alternative means of acquiring the data was to measure track mileage from maps. Detailed county maps show track routes and identify the owner. Generally this is only the main running track; railroads may have operating rights on track they do not own. In any case these mileages were measured for each of the Class I line haul railroads. When comparison was made between the measured track miles and the actual running track miles for those companies which returned that information, the average ratio of actual to measured was about two to one. This is because most running track is double track, which is not indicated as such on maps. Thus, the total miles of running track operated on by a Class I line haul railroad can be assumed to be two times the mileage obtained from a map measurement.

The information provided by the railroads answering the survey also show that, at least in the Chicago area, the miles of yard switching track nearly equals the miles of running track. This is undoubtedly only true for a major railroad area, because nationwide about 20% of the total track is in switchyards [2]. But as an estimate for the railroads not answering the survey, the miles of switchyard track in the Chicago AQCR is set equal to the miles of running track over which they operate.

The next step is to determine the operating statistics for each Class I line haul railroad. This is published annually by the Association of American Railroads [3]. The data relevant to this analysis are 1) the locomotive unit-miles accumulated in road service and train switching, and 2) the locomotive yard switching hours. These data are compiled for each of the sixteen railroads for 1973 freight and passenger traffic. Other necessary information is each railroad's total miles of running track and total miles of switchyard track [2].

It is now possible to estimate the activity of Class I line haul locomotives in the AQCR. First, the locomotive unit-miles each railroad operated in line haul in the Metropolitan Chicago AQCR in 1973 is calculated by the equation:

$$\frac{\text{Miles of line haul operation in AQCR}}{\text{Miles of line haul operation in U.S.}} = \frac{\text{Miles of running track in AQCR}}{\text{Miles of running track in U.S.}}$$

Similarly, the hours accumulated by each railroad's locomotives in switchyard activity in the region is calculated by:

$$\frac{\text{Hours of switchyard activity in AQCR}}{\text{Hours of switchyard activity in U.S.}} = \frac{\text{Miles of switch track in AQCR}}{\text{Miles of switch track in U.S.}}$$

Table 16 lists, for each Class I line haul railroad, the locomotive-miles of line haul operations and locomotive-hours of switchyard activities estimated to have occurred in the Chicago AQCR in 1973. The totals indicate that 1.3% of the U.S. line haul miles take place in this region, and 7.9% of the total U.S. switchyard hours.

The hours recorded in line haul operation are determined by dividing locomotive unit-miles by the average locomotive speed. The questionnaire sent to fifteen railroads asked the company to list the average speed of a freight train in each county of the AQCR. The speeds vary from 20 to 45 mph, with an average of about 28 mph. This is the average speed of a moving train, however. What is needed for an analysis of air pollution is the total locomotive operating time in the region,including stops. The average speed of all U.S. trains during 1973 was 20.0 mph (total train-miles ÷ total train-hours) [2]. This is assumed appropriate for the Chicago area, and it is used to estimate the locomotive-hours of line haul operation by Class I railroads as shown in Table 16.

The three Class I switching and terminal railroads in the Chicago region perform no line haul operations. They do carry out extensive terminal and transfer service. They are required to file regular reports with the U.S. Interstate Commerce Commission stating the hours of switching service they record. This information is not published by ICC but it is public. In 1972 (latest available at that time) the three Class I switching and terminal railroads accumulated 923,050 hours of yard activity [4]. In some instances car switching or transferring is done by more than one locomotive, but for this analysis the conservative assumption is made that the above figure is synonomous with locomotive-hours.

TABLE 16

LOCOMOTIVE OPERATION BY CLASS I RAILROADS IN THE CHICAGO AQCR, 1973

Railroad	Miles of Line Haul Operation	Hours of Switchyard Activity
ATSF	1,378,000	97,900
BN	784,800	144,900
BO	442,000	52,200
CO	413,000	53,000
CEI	425,600	52,000
CNW	2,461,000	471,700
MILW	1,445,000	80,600
CRIP	839,800	95,800
EJE	926,100	456,600
EL	518,600	50,600
GTW	667,200	32,600
ICG	1,758,000	347,000
LN	917,600	94,100
NW	1,909,000	172,200
PC	3,382,000	424,800
SOO	203,600	24,700
TOTAL	18,470,000	2,651,000

Hours of Line Haul Operation = 18,470,000 Miles ÷ 20 MPH
= 924,000 Hours

The only railroad activity left to be accounted for is that by Class II railroads. Most of these also perform switching service, but a few have limited line haul operations. By using data from Class I companies it is found that the average switch locomotive is used 6,130 hours a year. The contribution of Class II railroads to the regional railroad activity is estimated by assuming each of their switch locomotives operates the average annual hours. Class II railroads own 49 locomotives, so their total estimated hours of switchyard activity is about 300,000 hours.

Average Engine Size

Before determining the average horsepower of a locomotive, the population must be classified by engine type. The U.S. diesel locomotive population as of January 1, 1973, was 27,600 units [5]. Since about 93% of these are owned by Class I line haul railroads, statistics of these companies can be used to show that 75.5% of the units are used in line haul operation and 24.5% in switchyard service [3]. Determining the percentage that are 2 and 4-stroke is relatively simple. Over 96% of all locomotive engines are produced by three companies: Electro-Motive Division of General Motors Corp., Alco, and General Electric. Engines made by EMD are 2-stroke, all others are 4-stroke.

A railroad journal publishes an annual summary of locomotive ownership [5]. Locomotives owned by each railroad are listed according to engine manufacturer and horsepower. The assumption can be made that the switch locomotives are those of least horsepower. By compiling the make and size of the 6,800 switch engines (24.5% of

27,600), the average rated horsepower is found to be 1091 hp. And 70% of switch locomotives operate on a 2-stroke cycle. All switch locomotive engines are Roots-blown.

Performing similar calculations with the 20,800 locomotives used in road service yields an average rated horsepower of 2228 hp. Engines manufactured by EMD power 80% of all line haul locomotives. Generally those of lower horsepower are Roots-blown rather than turbocharged. And a reasonable estimate is that, of the 2-stroke line haul units, half are Roots-blown, half are turbocharged. Essentially all 4-stroke line haul locomotives are turbocharged.

To summarize, the line haul locomotive population is estimated to be 40% 2-stroke Roots-blown, 40% 2-stroke turbocharged, and 20% are 4-stroke engines. By assuming all engine types receive equal usage the locomotive-hours which have been estimated in the preceding section can now be apportioned according to the percentages represented by each engine type. A summary of all hours of locomotive operation in the Chicago AQCR by engine type is listed in Table 17 .

Average Engine Load Factor

The load factor is the average power produced during operation divided by the maximum available power. Most diesel locomotives have eight throttle positions, idle, and a dynamic brake. Because large diesel engines are difficult to start, they often run 24 hours a day. Thus, any typical locomotive duty cycle must be heavily weighted in the idle mode. At this time the best available estimates of average duty cycles for line haul and switch locomotives are the so called "EMD line haul cycle" and the "ATSF switch cycle" [8,9]. It is generally agreed that line haul locomotive operation is less variable than that of switchers because of the extended time spent in a given throttle position. Therefore, more confidence is expressed in the line haul cycle.

TABLE 17

ESTIMATED HOURS OF LOCOMOTIVE OPERATION IN THE METROPOLITAN CHICAGO AQCR, 1973

Engine Type	Locomotive-hours
Switch Engines	
2-stroke Roots-blown	2,712,000
4-stroke Roots-blown	1,162,000
Line Haul Engines	
2-stroke Roots-blown	369,600
2-stroke Turbocharged	369,600
4-stroke Turbocharged	184,800
Total	4,798,000

An extensive discussion of these duty cycles can be found in the report by Southwest Research Institute on locomotive emission tests done for the U.S. Environmental Protection Agency [6]. The load factors derived from the duty cycles are 0.397 for line haul locomotives, and 0.051 for switch units. These figures reflect the substantial amount of time a locomotive spends at idle.

Emission Factors

The emission factors which are used in this analysis are listed in Table 18 . They are taken from the Southwest Research Institute emission tests [6]. SWRI measured emissions from three locomotives of "in service" condition. The engines were a 2-stroke Roots-blown switcher and a 2-stroke and 4-stroke turbocharged line haul engines. Emissions at each throttle position were weighted according to the aforementioned duty cycles.

Two other groups have also studied locomotive exhaust emissions. One is the Association of American Railroads in conjunction with three large railroad companies [8]. The other is Electro-Motive Division of General Motors Corp., the world's largest manufacturer of locomotive engines [9]. The emission factors, in grams of pollutant per horsepower-hour, from these tests, in general, agree quite well with those of SWRI.

Sulfur oxides emissions were not measured by SWRI. The factors in Table 18 are derived from average specific fuel consumption data from the SWRI measurements over the appropriate duty cycle. All sulfur in the fuel is assumed to be oxidized during the combustion process and emitted as SO_2. The sulfur content of typical locomotive diesel fuel is 0.40% by weight [8].

Base Year Emissions

Exhaust emissions from locomotives are calculated from the following equation:

(Hours of locomotive operation in AQCR) x (Avg engine hp)
x (Avg load factor) x (Grams of pollutant/hp-hr)
x (Unit conversion factor) = Tons of pollutant/year

Emissions from each engine type in line haul and switchyard operation are estimated for the Metropolitan Chicago Air Quality Region in 1973. The results are shown in Table 19 .

TABLE 18

LOCOMOTIVE EMISSION FACTORS

Engine Type*	HC	CO	NO_x	SO_x
	Grams per Horsepower-hour			
2-s RB Switch	8.87	3.89	11.4	2.62
4-s RB Switch	4.96	12.9	16.6	1.93
2-s RB Line Haul	3.95	1.76	9.45	1.52
2-s TC Line Haul	0.695	4.00	8.22	1.40
4-s TC Line Haul	2.19	4.08	10.4	1.26

* Notation: 2-s = 2-stroke, 4-s = 4-stroke
RB = Roots-blown, TC = Turbocharged

Projected Growth Analysis

Predicting the growth of American railroads over the next 15 years is difficult, to say the least. The present mood seems to be one of optimism. One estimate in that by 1990 total train-miles in the U.S. will increase approximately 45% from 1970 levels [10]. Another cites the renewed interest in the nation's coal reserves as a prime factor in future railroad growth [11]. The 1975 edition on the Yearbook of Railroad Facts states that despite a coal strike at year's end, 1974 marked the third consecutive year of setting a traffic record as measured by freight ton-miles [12].

TABLE 19

EMISSIONS FROM LOCOMOTIVES IN THE METROPOLITAN CHICAGO AQCR, 1973

	Tons per Year			
Switchyard Activities	HC	CO	NO_x	SO_x
2-stroke RB Units	1,480	647	1,900	436
4-stroke RB Units	354	920	1,180	138
Total	1,830	1,570	3,080	574
Line Haul Operations				
2-stroke RB Units	1,420	634	3,410	548
2-stroke TC Units	250	1,440	2,960	505
4-stroke TC Units	395	735	1,870	227
Total	2,070	2,810	8,240	1,280
Total Emissions	3,900	4,380	11,300	1,850

Notation: RB = Roots-blown, TC = Turbocharged

Railroads can certainly provide an energy efficient means of transportation. The increased use of containers and piggyback loadings and continued strong farm output further point to a brighter future than railroads have seen in many years. And possibly most critical is the awareness by government officials that investment in the rail network and consolidation, such as ConRail and Amtrak, is risky but necessary for a healthy and balanced national transportation system.

With these considerations in mind railroad operation, as indicated by locomotive-miles in line haul service, and locomotive-hours in switchyard activity, is predicted to grow at a slow but steady rate at least until 1990. An annual growth rate of 3.0% per year is projected, and this applies to the U.S. railroad industry in general and all Air Quality Control Regions.

Predictive Computer Program

The computer program which can be used to estimate mass emissions from locomotives in any Air Quality Control Region in the country is listed in Appendix 3. Emissions are calculated for 2 and 4-stroke engines in switch locomotives (Roots-blown), and in line haul locomotives (all 4-stroke are turbocharged, 2-stroke emissions are the sum of turbocharged and Roots-blown engines).

The only factor which is unique for each AQCR is the hours of locomotive operation in the region. All other parameters--average horsepower, emission factors, etc.--are applicable to every AQCR and are assigned constant values in the program. The only indication of railroad traffic in a given county (AQCR's are groups of counties) is the amount of track within the county. By apportioning locomotive activity on the basis of track mileage one must accept the assumption that every mile of non-abandoned track in the U.S. carries an equal share of the total railroad traffic. This is obviously untrue. Track in major transportation centers such as Chicago, New York, and San Francisco carries much more traffic than do rural branch lines. But as previously discussed, there is no justification for arbitrarily choosing a track usage factor that is applicable to all (or even some) AQCR's. Therefore, until other information becomes available, total U.S. railroad traffic, as defined by locomotive-miles or locomotive-hours, will be apportioned to AQCR's in direct relation to the miles of track within the region. A user of the computer program is cautioned to view the estimated emissions with an understanding of these qualifications. If the user has knowledge that track in a particular AQCR carries, say, twice as much traffic as the average mile of U.S. track, then the computer generated emissions should by multiplied by two. One final note is that the re-organization of the six Northeastern railroads into ConRail may eventually delete thousands of miles of unprofitable branch lines from the system. This action will even the load over all track that remains in use, and by revising the computer program accordingly, will lessen the inherent error of the present calculations.

A user of the program must first decide how the track mileage is to be determined. There are two possible methods. The first, and most accurate, is to actually measure the miles of track from detailed county maps. Most maps do not show yard track. Generally, only main running track is shown. If this is the case, then the user should multiply the mileage by two to account for double track, way switching track, turn-outs, crossovers, etc.. As shown by the analysis of Chicago AQCR, the total miles of running track in the region is about equal to twice the mileage obtained from map measurements.

The alternative method for determining running track mileage is to estimate it from two indicator parameters. The computer program contains an equation which estimates the miles of running track in an AQCR from 1) the number of retail trade establishments and 2) the number of manufacturing establishments. The equation is developed from data collected during the Chicago AQCR analysis. The miles of running track in eleven counties were known from surveys of railroad companies and map measurements. A multiple linear regression analysis was performed with county track mileage as the dependent variable. Seven different independent parameters were analyzed. The two most influential are the number of manufacturing establishments, and the number of retail trade establishments in each county. The multiple correlation coefficient shows significance at the 99% level ($R^2 = .968$) for the equation:

$$\text{Miles of running track in a county} = (157.7) - (0.394 \times \text{MANUF}) + (0.149 \times \text{RETAIL})$$

where "MANUF" and "RETAIL" are the number of manufacturing and retail trade establishments, respectively. These parameters are easily obtained for any county from the County and City Data Book, 1972 [13]. The data are for 1967, but those are the most current at this time. The above equation is adapted in the program to estimate running track mileage for AQCR's which are usually a cluster of counties. Of course, it must be realized that the regression was performed using data from only eleven counties in the Chicago area. It would be preferable to have used a sampling of counties around the country. The equation probably has greater validity for metropolitan rather than rural areas. In the case of rural areas, however, map measurements would be much simpler, and that is the recommended method.

With the determination of running track mileage the next step is to estimate switchyard track mileage in the AQCR. From the Chicago analysis yard mileage is approximately equal to running mileage. In the U.S. as a whole yard mileage is only 20% of total track. To compensate for this inequity the user must designate whether the AQCR being analyzed is a major railroad terminal center or not. If it is, and most major cities are in this category, then the program automatically sets the switchyard mileage equal to the previously determined running track mileage. If the AQCR is not considered a major terminal center, and hence does not have extensive yard area, the miles of switchyard track are assumed to equal 25% of the running track mileage (20% of total mileage).

Now the program is ready to estimate locomotive-hours of line haul and switching operation. For line haul operation the equations are:

$$\frac{\text{Miles of line haul operation in AQCR}}{\text{Miles of line haul operation in U.S.}} = \frac{\text{Miles of running track in AQCR}}{\text{Miles of running track in U.S.}}$$

Hours of line haul operation in AQCR =

$$\text{Miles of operation in AQCR} \div \text{Average locomotive mph}$$

Fixed values in these equations are the total locomotive-miles of line haul operations in the U.S. ($1,510 \times 10^6$ miles); total miles of running track in the U.S. (284,800 miles); and the average speed of a line haul locomotive (20.0 mph) [2]. It should be noted that all the figures cited in this analysis are for 1973.

The equation for switchyard activity is:

$$\frac{\text{Hours of switchyard activity in AQCR}}{\text{Hours of switchyard activity in U.S.}} = \frac{\text{Miles of switch track in AQCR}}{\text{Miles of switch track in U.S.}}$$

The fixed values are the total hours of switchyard activity in the U.S. (40.83×10^6 hours); and total miles of switching track in the U.S. (61,780 miles) [2,3,4].

A summary of the user-supplied input data needed to run the computer program is:

1. "JRUN" index, either 0 or 1. If JRUN=0, the user desires the program to estimate the miles of running track in the AQCR. The following indicator parameters must then be input:
   a. The number of counties in the AQCR
   b. The number of manufacturing establishments in the AQCR
   c. The number of retail trade establishments in the AQCR

   If JRUN=1, the user must input the miles of running track in the AQCR directly; the three indicator parameters are, therefore, not needed.

2. "KYARD" index, either 0 or 1. If KYARD = 1, the user has designated the AQCR a major railroad terminal center. The program sets switchyard track mileage in the AQCR equal to running track mileage in the AQCR. If KYARD = 0, the user has designated that the AQCR has an average amount of yard track, and switchyard track mileage is set equal to 25% of running track mileage.
3. Projected growth rate of railroad traffic in the AQCR through 1990, in percent increase per year.

A complete description of the required format for the input data is included in Appendix 3.

Figure 8 is a sample of the printed computer output. The estimated hours of locomotive operation in line haul and switchyard service are listed according to engine type, as well as corresponding exhaust emissions. The estimates are for the Metropolitan Chicago AQCR during 1973. There are slight differences between these emissions and the values in Table 19 . The computer estimates are calculated using more generalized equations.

Figures 9 through 12 are graphs showing the projected trend of locomotive emissions in the Chicago AQCR through 1990 for each of four pollutants. The curves reflect the projected growth rate of railroad activity which is 3.0% per year.

```
YEAR    1973

          ESTIMATED LOCOMOTIVE - HOURS :

LINE HAUL OPERATIONS
  2 STROKE UNITS                 864003.
  4 STROKE UNITS                 216001.

SWITCHYARD ACTIVITIES
  2 STROKE UNITS                1884724.
  4 STROKE UNITS                 807739.


                                      EXHAUST EMISSIONS  (TONS PER YEAR)
                                HC            CO            NOX            SOX

LINE HAUL OPERATIONS
  2 STROKE UNITS               1956.         2426.         7443.          1230.
  4 STROKE UNITS                461.          859.         2190.           265.
  TOTAL                        2418.         3285.         9633.          1496.

SWITCHYARD ACTIVITIES
  2 STROKE UNITS               1025.          450.         1318.           303.
  4 STROKE UNITS                246.          639.          822.            96.
  TOTAL                        1271.         1089.         2140.           399.

TOTAL EMISSIONS                3689.         4374.        11773.          1895.
```

Fig. 8. Sample output of locomotive computer program

FIGURE 9

PROJECTED LOCOMOTIVE EMISSIONS : HC

METROPOLITAN CHICAGO AQCR

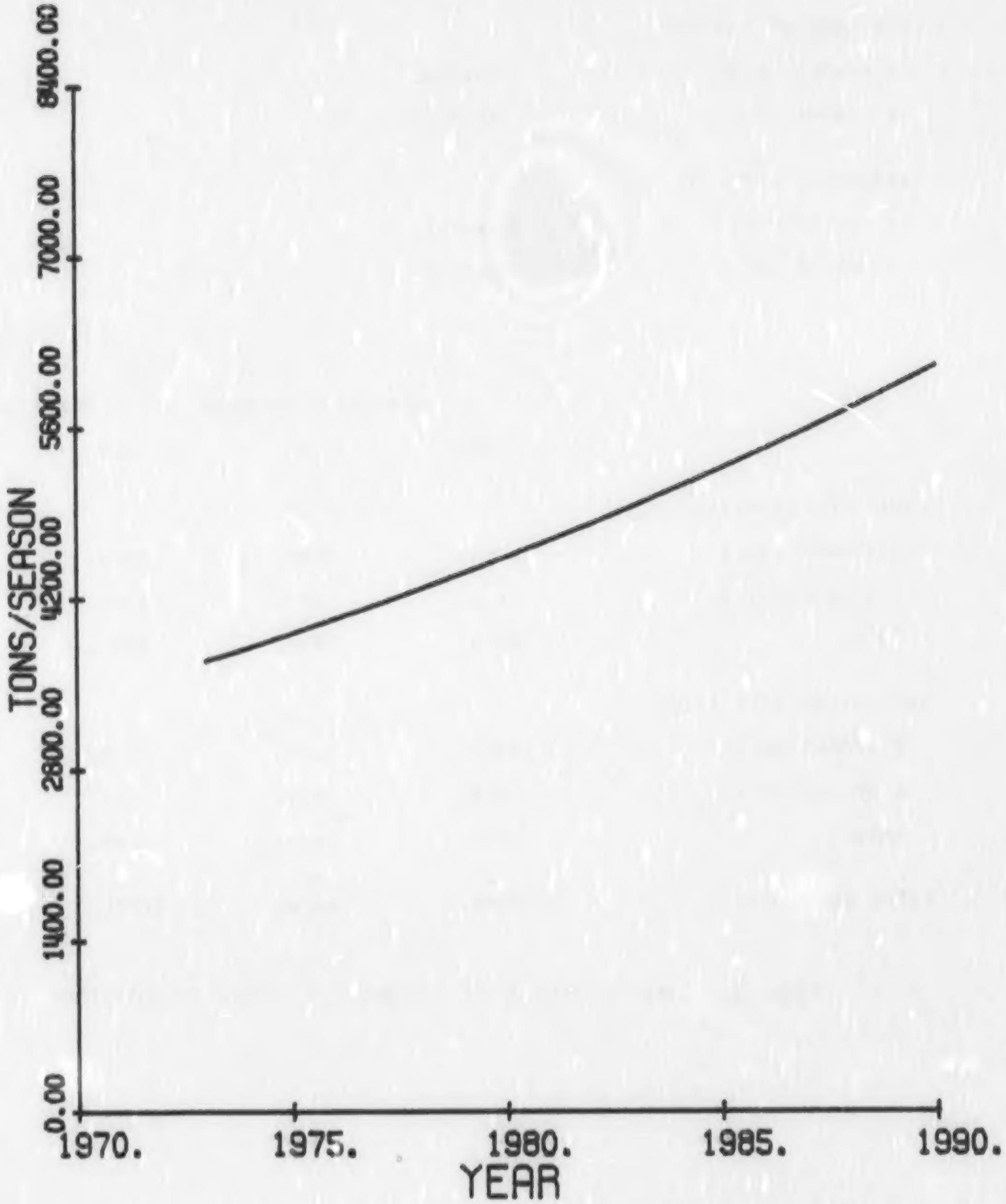


FIGURE 10

PROJECTED LOCOMOTIVE EMISSIONS : CO

METROPOLITAN CHICAGO AQCR

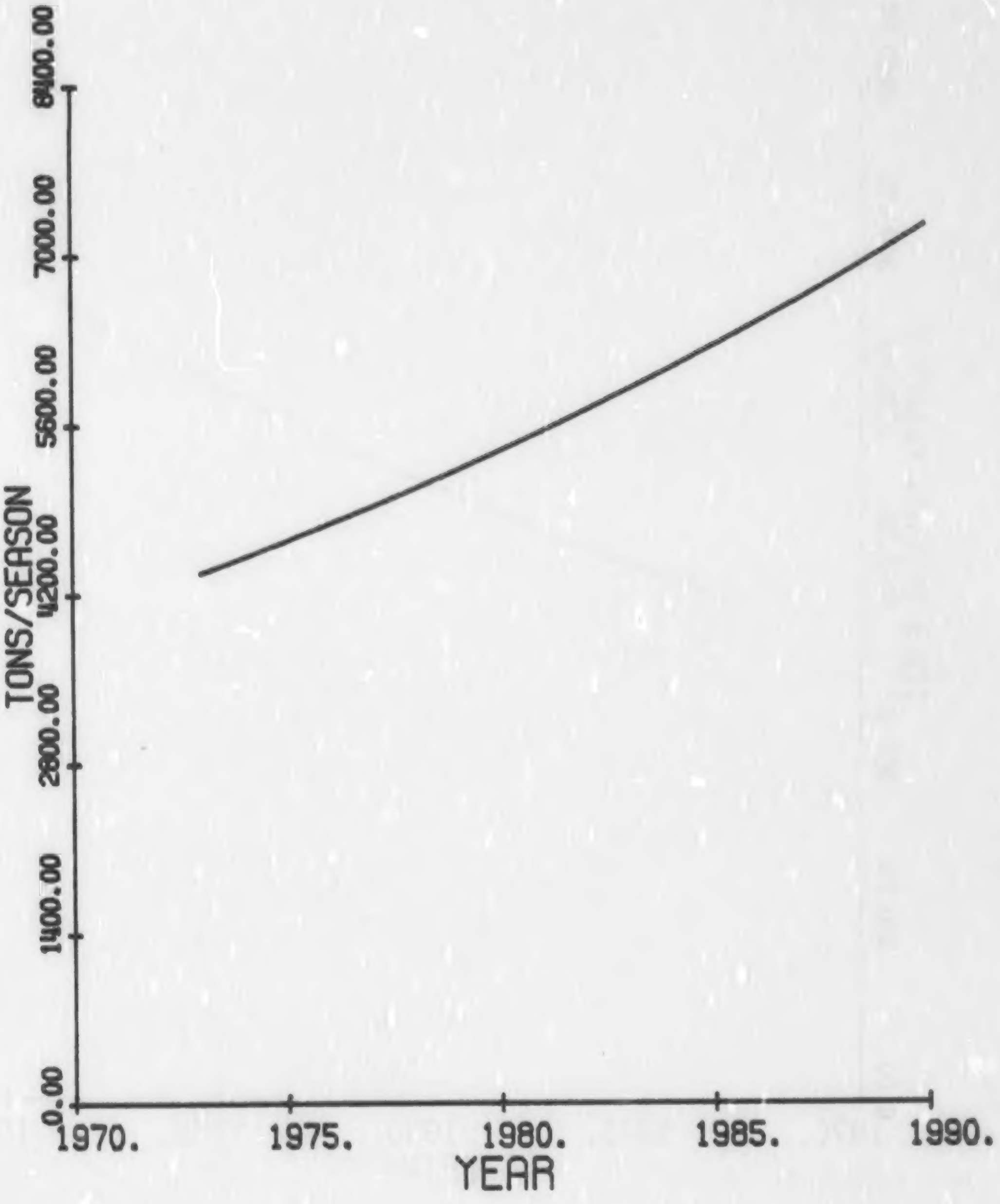


FIGURE 11

PROJECTED LOCOMOTIVE EMISSIONS : NOX

METROPOLITAN CHICAGO AQCR

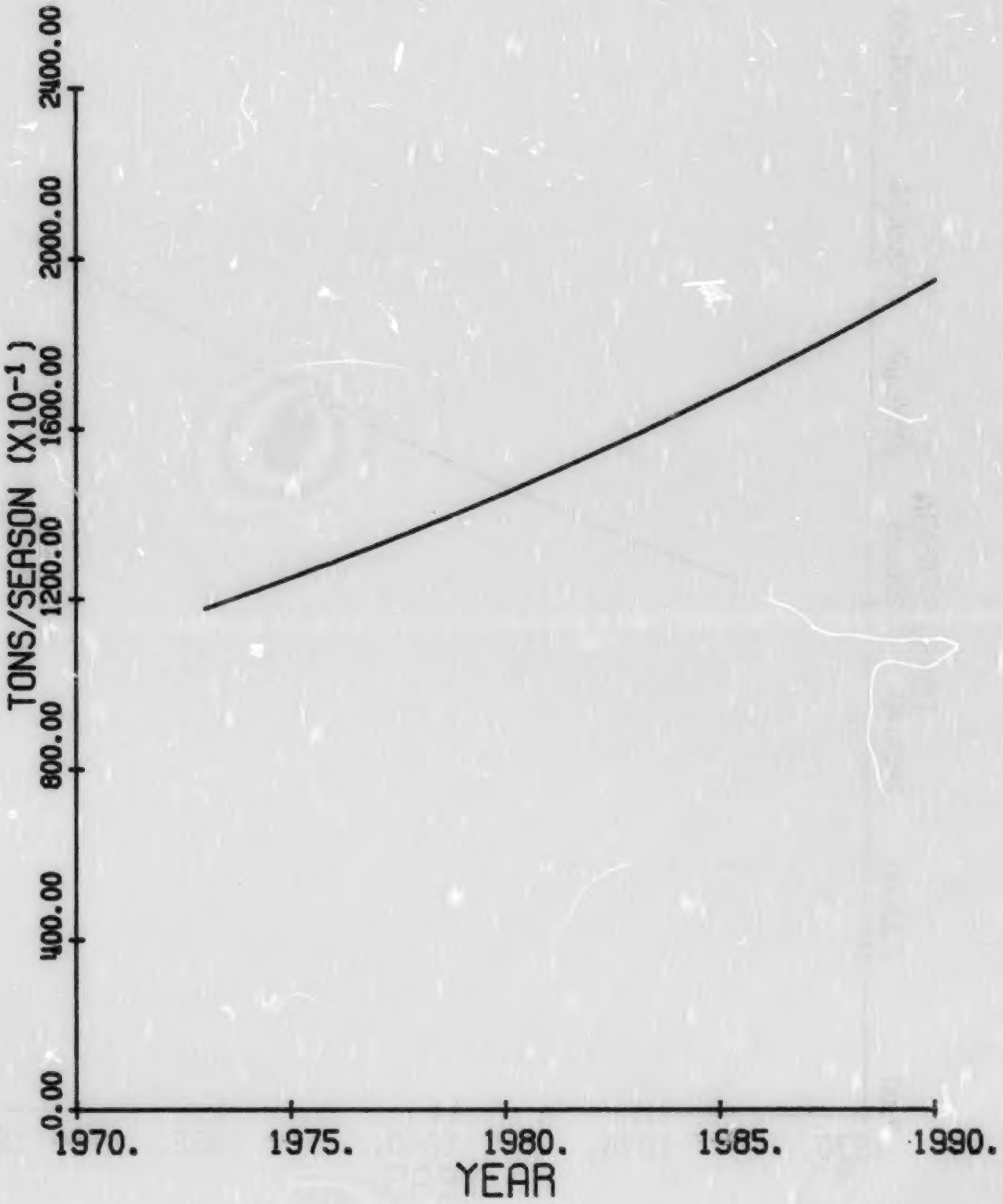
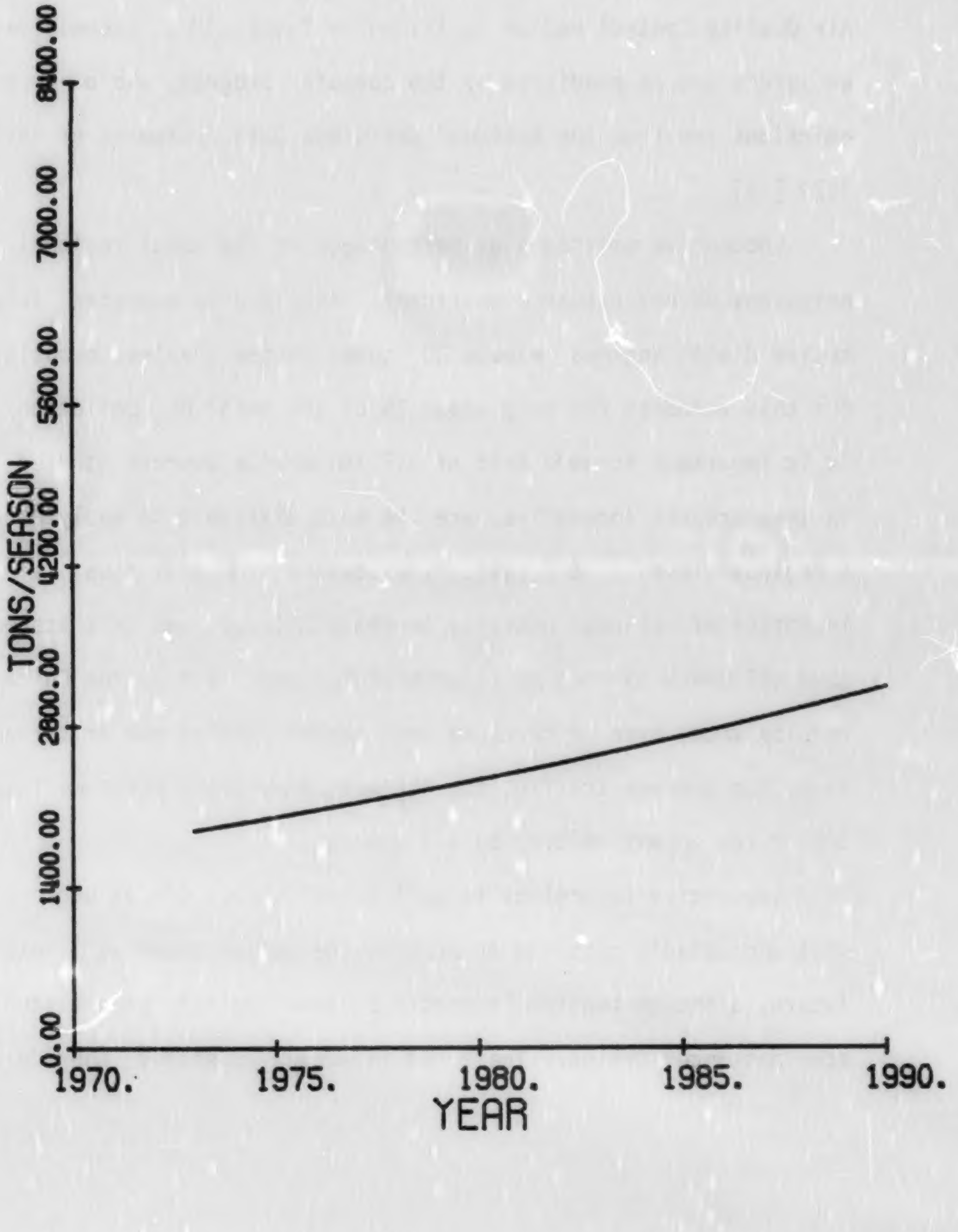


FIGURE 12

PROJECTED LOCOMOTIVE EMISSIONS : SOX

METROPOLITAN CHICAGO AQCR



Comparison with Other Air Pollution Sources

The 1976 emissions inventory for the Metropolitan Chicago Air Quality Control Region is listed in Table 20 . Locomotive emissions are as predicted by the computer program, and other source emissions are from the National Emissions Data System as of May 1, 1976 [14].

Locomotive emissions as percentages of the total regional emissions do not appear significant. As could be expected, locomotive diesel engines release NO_x gases in the greatest quantity. but this accounts for only about 3% of the total NO_x pollution. It is important to note that of all the mobile sources studied in this project locomotives are the most difficult to analyze on a regional level. As previously discussed, the only possible indicator of railroad activity is track mileage, and this assumes that all track carries an equal traffic load. But as the Chicago results show, even if track in this region carries two or three times the average traffic, the NO_x emissions would still be less than 10% of the amount emitted by all sources.

Locomotive technology is well established. Diesel engines will undoubtedly continue to provide the motive power well into the future, although turbine locomotives have recently been tested on some passenger trains. The trend in annual emissions, therefore,

TABLE 20

EMISSIONS INVENTORY FOR THE METROPOLITAN CHICAGO AQCR, 1976

Source	Tons per Year			
	HC	CO	NO_x	SO_x
Locomotives	4,031	4,780	12,865	2,070
Light Duty Vehicles	258,923	1,469,120	177,787	5,304
Heavy Duty Vehicles	36,422	196,293	42,600	3,620
Aircraft	6,369	14,284	4,336	487
Gasoline Handling Evap. Loss	37,387	--	--	--
Industrial Processes	183,172	186,588	13,136	34,694
Electric Generation	994	3,400	111,072	294,958
Fuel Combustion (Indust., Resid., and Commercial)	10,679	38,854	94,392	183,509
Solid Waste Disposal	38,236	116,471	6,983	3,946
Miscellaneous	184,118	--	--	--
Total Emissions	760,331	2,029,790	463,171	528,588
Locomotives as % of Total Emissions	0.5	0.2	2.8	0.4

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

is projected to be a slow but steady increase at least for the next fifteen years. This is illustrated for the Chicago AQCR in Figures 9 through 12 . It can be concluded that locomotives do not appear to be a significant source of pollution in urban areas at the present time. But as laws regulating emissions from light and heavy duty vehicles, and stationary sources continue to be implemented, locomotive emissions may attain greater importance.

PART 4

LAWN AND GARDEN IMPLEMENTS

Nearly half the households in the United States use power lawn mowers regularly during the grass growing season [1]. Many own, borrow or rent other lawn and garden implements such as garden tractors and motor tillers. Add to this the sizable number of powered implements used by professional landscapers, golf courses, municipalities, parks, cemeteries, and commercial establishments, and the result is about 50 million gasoline powered lawn and garden implements in use today. They are a source of air pollution concentrated in densely populated areas and occuring during warm weather which can be a factor in formation of photochemical smog.

This Part is concerned with emissions from the category of lawn and garden implements. The category is divided into the following implement types.

1. Walk-behind power lawn mowers using 2-stroke or 4-stroke engines
2. Riding mowers (also called lawn tractors)
3. Garden tractors
4. Motor tillers (also called rotor tillers or self-powered rotary plows)

These implements are all powered by air-cooled gasoline engines. There are other power implements in use, such as grass and hedge trimmers, edgers, and some lawn mowers that operate by electric power, but these are not included in this analysis. Specialized power implements such as yard vacuums, shredders, grinders, etc., also are not covered because their numbers are insignificant. Chain saws and snow throwers are two implements that may be significant but are not included for the following reasons. Chain saws are more often used in rural than in urban areas. Snow throwers are used in northern states during winter months when all other lawn and garden implements are not being used.

The difference between a riding mower and a garden tractor should be noted. A riding mower is a self-propelled unit whose primary purpose is mowing grass. Riding mowers often can be equipped with attachments for garden work also, but, in general, riding mowers are less horsepower than garden tractors and have non-removable grass cutting apparatus.

Estimation of Emissions in a Selected AQCR

This section describes the method used to estimate exhaust emissions from lawn and garden implements. The selected Air Quality Control Region is Detroit-Port Huron, Michigan. This region is chosen because it encompasses a major metropolitan area, and its housing characteristics are dominated by single unit dwellings. The AQCR consists of the following counties in Michigan.

Macomb
Oakland
St. Clair
Wayne

This region covers 2,650 square miles, and its 1970 population was 4.32 million.

The use of lawn and garden implements is seasonal, so emissions are estimated on this basis. Most lawn and garden activity occurs between mid-May and mid-October in this region; hence, emissions represent the five month season of 1974.

The following parameters are needed to determine emissions caused by each type of lawn and garden implement.

1. Implement population in AQCR
2. Average implement usage (hours per season)
3. Average engine size (horsepower)
4. Average engine load factor
5. Emission factors (grams of pollutant per horsepower-hour)

Implement Population in AQCR

The first step toward determining the 1974 population of implements in the Detroit AQCR is to determine national populations. Good data are available from two sources. The first are the results of a nationwide survey of households conducted for the Consumer Product

Safety Commission (CPSC) [1]. The survey attempted to assess consumer attitudes and behavior concerning safe use of outdoor power equipment. Through the use of a national probability sample the survey projected that 30.0 million households owned gasoline powered lawn mowers in 1974. The second source of population data is the Outdoor Power Equipment Institute (OPEI), a trade association which represents manufacturers of outdoor power equipment. In its annual statistics release of 1974 OPEI estimated that 40 million power lawn mowers (walk-behind and riding) were in use in the U.S. [2]. The discrepancy between the two figures appears substantial until it is realized that CPSC's survey included only lawn mowers owned by households, and not units owned by commercial establishments, etc.. Furthermore, the survey did not identify households with multiple ownership of mowers. For these reasons it is decided to use as the 1974 population of power lawn mowers the OPEI figure of 40 million units.

The next step is to separate walk-behind mowers and riding mowers, since both are included in the 40 million unit estimate. The CPSC survey proved useful, since their interview included a question about the type of mower owned. The results showed 88% of the mowers were walk-behind types, and 12% were riding types. This agrees very well with OPEI data which show 87.2% of the mowers produced between 1970 and 1974 were walk-behind. Thus, the 1974 population of walk-behind mowers is estimated to be 88% of 40 million, or 35.2 million units. The riding mower population is estimated as 4.8 million units.

Garden tractors are less popular than riding mowers. The CPSC survey projected a national population of 2.4 million units with an average age of 5.6 years. Comparing this to OPEI's annual garden tractor production data, it becomes apparent that the only way there could be 2.4 million garden tractors in use today is if every unit produced since 1966 were still operating. This seems unlikely. The conflict appears to be a lack of distinction between a garden tractor and a riding mower . Undoubtedly some respondents to the survey said they owned a garden tractor, when in fact it was a tractor designed primarily to mow grass. In any case the 1974 garden tractor population is estimated from annual production data applied to an average age of 5.6 years.

1974 Garden tractor population = (Units produced, 1970-74)
+ (0.6 x Units produced in 1969) = 1.5 million units

The final implement is motor tillers. The CPSC survey neglected this implement, so population is derived from OPEI annual production data assuming an average age of 6 years. This is slightly greater than the age of a garden tractor, but a tiller is a highly specialized unit which would experience less operating time per season so its service life should be somewhat longer.

1974 Motor tiller population=
(6 x Average annual unit production, 1969-74)
= 3.0 million units

As previously stated all lawn and garden implements are powered be gasoline engines, the vast majority of which operate on a 4-stroke cycle. Since emission characteristics differ significantly between 4-stroke and 2-stroke engines, it is necessary to identify the implement populations by engine type. Previous studies in this area indicate that more than 90% of the engines are 4-stroke [3,4]. Currently, 2-stroke engines are being manufactured for use in rotary lawn mowers, but safety considerations concerning high blade tip speeds are phasing them out of the market [5,6].

For this analysis it is assumed that in the 1974 population 95% of walk-behind lawn mowers have 4-stroke engines, and all riding mowers, garden tractors, and motor tillers are powered by 4-stroke engines. Table 21 lists a summary of the 1974 lawn and garden implement population in the U.S..

There are no data available on implement populations by state or metropolitan area. A previous study suggests that populations are proportional to the number of owner-occupied housing units in a state [6]. The 1970 Census of Housing shows that approximately 90% of owner-occupied housing units in the U.S. are single unit dwellings [7]. The rationale follows that the majority of lawn and garden implements are owned by occupants of these dwellings. Furthermore, in order to estimate the implement population for an Air Quality Control Region it is necessary to have data on a county basis. Thus, it is decided to base the AQCR implement population on the proportion of owner-occupied housing units in the region. The most recent housing data are for 1970, but it will be assumed that the 1974 ratios do not differ significantly.

From the 1970 Census of Housing the four counties which comprise the Detroit-Port Huron AQCR are found to have 942,140 owner-occupied housing units (OOHU). The U.S. total is 39,885,180. The following equation is used to estimate AQCR implement population.

$$\frac{\text{Implements in AQCR}}{\text{Implements in U.S.}} = \frac{\text{OOHU in AQCR}}{\text{OOHU in U.S.}}$$

Using the U.S. implement population data from Table 21 the AQCR populations are calculated. Table 22 is a summary of the estimated 1974 lawn and garden implement population in the Detroit-Port Huron AQCR.

Average Implement Usage

Factors which influence the annual usage of lawn and garden implements are length of the growing season and the area of lawn or garden to be tended. Previous researchers have estimated average usage to be between 30 to 70 hours per year, with most agreeing that 50 hours is a reasonable average [3,4,6]. The Outdoor Power Equipment Institute suggests lawn mowers and motor tillers are used about one hour a week during the growing season by a typical household [8]. The only hard data published are results of the Consumer Product Safety Commission's survey [1]. The answers of respondents concerning frequency and duration of use show that the average household uses its power lawn mower once every 7 to 10 days; operating it for little more than

TABLE 21

ESTIMATED LAWN AND GARDEN IMPLEMENT POPULATION
IN THE UNITED STATES, 1974

Walk-behind Lawn Mowers	35,200,000
Using 2-stroke Engines	1,760,000
Using 4-stroke Engines	33,400,000
Riding Mowers	4,800,000
Garden Tractors	1,500,000
Motor Tillers	3,000,000

TABLE 22

ESTIMATED LAWN AND GARDEN IMPLEMENT POPULATION
IN THE DETROIT-PORT HURON AQCR, 1974

Walk-behind Lawn Mowers	832,000
Using 2-stroke Engines	42,000
Using 4-stroke Engines	790,000
Riding Mowers	113,000
Garden Tractors	35,400
Motor Tillers	70,900

an hour and a half each time. Applied to a five month growing season, this is about 25 hours of use per year.

It should be noted that usage as defined here is the total time the engine is operating (and emitting pollutants), not simply the time spent actually cutting grass. Also, the CPSC survey applies only to implements owned by households. There is no information available on the usage by non-households, but obviously such users as professional landscapers, and golf courses will accrue a much greater seasonal usage, with some equipment being operated every day. The following procedure can be used to estimate seasonal usage of all lawn mowers.

1. From previous data there are 35.2 million walk-behind lawn mowers in the U.S.
2. Assume 15% of these are owned by non-households (data indicate 20% of lawn and garden equipment dollar sales are by non-households [1])
3. Let average use by household be 25 hours per season
4. Let everage use by non-household be 200 hours per season (10 hours per week for 20 weeks)

The above scheme results in a lawn mower use of 50.8 hours per season. This agrees with estimates of other researchers. Therefore, this analysis will use 50 hours per season as the average usage of a walk-behind lawn mower, or to state it another way, for the Detroit AQCR usage is 10 hours per month over a five month growing season.

The usage of a riding mower or garden tractor can be expected to be greater than that of a walk-behind mower because a greater percentage of them are used in commercial operation. Even those owned by households probably receive high usage in order to justify their purchase price. The CPSC survey reveals the average household garden tractor is used once every 18 days for about 2.5 hours. Over a five month season this is close to 25 hours of use. By assuming equal usage for riding mowers and garden tractors the following method estimates average usage.

1. From previous data there are 6.3 million riding mowers and garden tractors in the U.S.
2. Assume 25% of these are owned by non-households
3. Let average use by household be 25 hours per season
4. Let average use by non-household be 300 hours per season (15 hours per week for 20 weeks)

This predicts an average usage for a riding mower or a garden tractor of about 95 hours per season, or 19 hours per month for a five month season.

The CPSC survey does not include motor tillers so there is very scant information on which to base a usage estimate. The function of a motor tiller would seem to indicate that heaviest use would occur at the beginning and the end of the season when soil is normally plowed. A motor tiller is a very specialized implement, and a single owner would not use it often. However, a unit may be borrowed or rented, and thus, accumulate more use. The average usage for motor tillers to be used in this analysis is 35 hours per season, or 7 hours per month for a five month season.

Average Engine Size

Engine size refers to the manufacturer's rated horsepower. Sufficient information is available about this parameter, and the following estimates have been derived for each of the implements.

1. The average rated horsepower of a walk-behind lawn mower (both 2 and 4-stroke) is estimated to be 3.1 hp [9].
2. The average horsepower of a riding mower is estimated to be 7 hp [5,10].
3. The average horsepower of a garden tractor is estimated to be 12 hp [5,10].
4. The average horsepower of a motor tiller is estimated to be 5 hp [5].

Average Engine Load Factor

Previous studies have estimated that lawn and garden implements in typical operation are generating between 40 and 70% of maximum rated horsepower [3,4]. The Outdoor Power Equipment Institute and a major implement manufacturer feel most users operate their equipment at or near full engine speed [5,8]. All engines are governed to operate at no higher than 80 to 85% of rated horsepower. Due to recent federal lawn mower safety regulations on maximum tip speed, the governed rpm varies with the size of the blade. For example, a typical walk-behind mower of 3.5 rated hp at 3600 rpm, would be governed to 3000 rpm and 2.5 hp. If the mower were developing maximum hp (not unusual) the load factor would be 0.71. The manufacturer of another common lawn mower engine recommends an operating range between 0.52 and 0.85 of rated hp [10].

Based on the above information an average load factor of 0.70 is considered reasonable for walk-behind lawn mower engines, both 2 and 4-stroke. Riding mowers and garden tractors are operated under widely varying conditions and loads, so an average load factor of 0.50 is chosen for each of these implements. Motor tiller engines almost always operate at full load conditions, so an average load factor of 0.80 is estimated.

Emission Factors

Emissions from engines used in lawn and garden implements have been measured in three previous studies. Tests were conducted by the Bureau of Mines on a large number of small horsepower engines [11]. The SAE 9-mode test cycle was used. This cycle represents engine load conditions similar to those which would be experienced in actual use (0.50 - 0.70). However, emissions were measured at only one speed for all engines (3600 rpm). Other tests were performed by Automotive Environmental Systems, Inc. [6]. AESI measured emissions from three lawn mowers and two motor tillers while the implements were actually mowing or tilling. These are the only tests ever conducted on the complete implement while in operation in the field (or on the lawn). This would be a good method if a baseline were being established with a very large sample of units tested through a typical duty cycle. Unfortunately, AESI did not know if their test procedure was typical. They did not measure engine speed or horsepower. The other source of small engine emission data is work done by Southwest Research Institute for the U.S. Environmental Protection Agency [4]. Five engines that have application in lawn and garden implements were tested using a modified EMA-California 13-mode procedure, which measures emissions at various speed and load settings. This duty cycle represents an overall load factor of about 0.40.

The results of the three separate emission studies do not greatly differ. Raw data from Bureau of Mines tests agree well with SWRI data. In general HC and CO emissions from AESI are greater than Bureau of Mines or SWRI emissions, and NO_x emissions are lower. A major reason for the difference is that AESI tested in-service implements, that is, they were not new, fully tuned engines such as those in the other two studies. Because the emission data do not differ significantly, emission factors for this analysis are derived from the SWRI tests.

Of the five engines tested only one was 2-stroke (a 2 hp Tecumseh), so its emission factors are used to calculate emissions from 2-stroke walk-behind mowers. The 4-stroke engines ranged in size from 3.5 to 18 hp. Ideally, a composite emission factor for each pollutant would be derived by weighting each engine's emission factor by its relative prevalence in the total lawn and garden implement population. But this information is not available (manufacturers hold it proprietary) and, since only four engines of this type were tested, an equal weighting (0.25) of each is used. Table 23 lists the composite brake specific emission factors derived for lawn and garden implements. The composite 4-stroke emission factor is used for all 4-stroke implements: walk-behind mowers, riding mowers, garden tractors and motor tillers.

TABLE 23

EMISSION FACTORS FOR LAWN AND GARDEN IMPLEMENTS

	Grams/Horsepower-hour		
	HC	CO	NO_x
Two-stroke Engines	214.	486.	1.58
Four-stroke Engines	20.5	295.	4.34

Base Year Emissions

Using the parameters indentified in the preceding sections it is possible to estimate seasonal mass emissions of HC, CO, and NO_x caused by lawn and garden implements in the Detroit-Port Huron Air Quality Control Region. The general equation is:

(Implement population in AQCR) x (Avg. hours of use/season)
x (Avg engine hp) x (Avg load factor) x (Grams of pollutant/hp-hr)
x (Unit conversion factor) = Tons of pollutant/season

Table 24 lists the estimated exhaust emissions from each type of lawn and garden implement for the 1974 season.

TABLE 24

EMISSIONS FROM LAWN AND GARDEN IMPLEMENTS IN THE DETROIT-PORT HURON AQCR, 1974

	Tons per Season*		
	HC	CO	NO_x
2-stroke Walk-behind Mowers	1,060	2,420	8
4-stroke Walk-behind Mowers	1,940	27,900	410
Total Walk-behind Mowers	3,000	30,300	418
Riding Mowers	852	12,300	180
Garden Tractors	456	6,570	97
Motor Tillers	224	3,230	47
Total Emissions	4,530	52,400	742

* Season is mid-May to mid-October: 5 months.

Projected Growth Analysis

The use of power lawn and garden implements has increased greatly in the past 15 years. From 1966 to 1974 annual sales increased over 50% to almost 8.5 million units a year [2]. This growth can be expected to continue with the general rise in national population and housing construction. Of course, lawn and garden implements could be major victims of a future fuel shortage, but it is impossible to predict if and when this might occur.

The most relevant information on which to base a projected growth rate is annual sales data as compiled by the Outdoor Power Equipment Institute. OPEI estimates that approximately 80% of sales are replacement, and 20% represent the increase to the total implement population [8]. It can be calculated that the yearly increase in U.S. implement population between 1969 and 1974 ranged from a 3.2% to a 4.1% increase. Based on these figures, and taking a conservative view that the growth rate will be somewhat lower over the next 15 years, an average annual growth rate of 3.0% per year is projected through 1990. This applies to each sub-category of lawn and garden implements in the U.S..

The only remaining question is whether 2-stroke engines will continue to be utilized in lawn mowers. As previously discussed, safety regulations concerning maximum cutting blade tip speed are causing the 2-stroke engine to be phased out. There were never many 2-stroke lawn mowers in use; the estimate is 5% of the 1974 population. They are still currently being produced, so they will remain in the population for a number of years at least. The assumption is made that the percentage of walk-behind mowers that have 2-stroke engines will decrease at a rate of 0.5% per year. Thus, in 1975 2-stroke engines are 4.5% of the mower population, and by 1984 they will have been phased out completely.

Predictive Computer Program

The computer program which can be used to estimate mass emissions of lawn and garden implements in any Air Quality Control Region in the country for any year from 1974 through 1990 is listed in Appendix 4. The program estimates emissions for the following types of lawn and garden implements.

1. Walk-behind lawn mowers (2 and 4-stroke)
2. Riding mowers and garden tractors
3. Motor tillers

(Note that the categories riding mowers and garden tractors have been combined to a single category.)

The parameters which can be considered independent of individual AQCR characteristics are emission factors, engine size and load factors, and implement usage (hours per month). Hence, they are assigned a constant value in the program and require no user input. The methods used to determine the assigned parameters are described in the previous sections. Input parameters for the category are 1) length of growing season, and 2) projected growth rate of the lawn and garden implement population in the AQCR.

Lawn and garden implement population in the AQCR is the most critical factor in the computation of air pollution. Obviously the greater the population, the greater the emissions. But there is no direct count of this population on a county level (the basic component of an AQCR). Therefore, an indicator parameter must be developed to permit a reasonable estimate to be made from available county data. As discussed in a previous section, the number of lawn and garden implements in a county can be assumed to be directly proportional to the number of owner-occupied housing units. This parameter can be obtained from the 1970 Census of Housing [7]. Even though the data are from 1970 in most instances any change would not be sufficient to invalidate its use in estimating the 1974 population of lawn and garden implements. This contention is further substantiated by the fact that AQCR's are composed of a number of counties, so in the case of a metropolitan area, even if the county which contains the central city has experienced a decline in housing units since 1970, the surrounding suburbs have probably undergone a proportional increase and they are part of the same AQCR.

To summarize, the input data and indicator parameter which must be supplied by the user of the computer program are:

1. Total number of owner-occupied housing units in the AQCR
2. Length of the growing season, in months
3. Projected growth rate of lawn and garden implement population in the AQCR, in percent increase per year

A complete description of the required format for the input data is included in Appendix 4.

The output of the computer program is presented here in two forms. Figure 13 is a sample of the printed output the user may request for any year between 1974 and 1990. The estimated implement population for the AQCR being analyzed is listed as well as the corresponding gaseous exhaust emissions in tons of pollutant per season. Figure 13 shows emissions in the Detroit-Port Huron AQCR for the base year of 1974, so it agrees with Table 24 .

The other output form is a graphical presentation of total emissions caused by lawn and garden implements over the time period

1974 through 1990. Figures 14 and 15 are the plots of the two major implement pollutants, HC and CO, in the Detroit-Port Huron AQCR, reflecting a projected growth rate of 3.0% per year.

It should be noted that the computer program incorporates a series of equations designed to reflect the phase out of 2-stroke walk-behind lawn mowers from a starting point of 5% of the mower population in the base year 1974, to complete elimination by 1984. This method is discussed in detail in the growth analysis section.

Comparison with Other Air Pollution Sources

Table 25 lists the emissions inventory of the Metropolitan Detroit-Port Huron Air Quality Control Region for a five month season in 1975. Emissions from lawn and garden implements are as predicted by the computer program, and other source emissions are from the National Emissions Data System as of June, 1975 [12]. Since the use of lawn and garden implements is seasonal in this region, the NEDS data, which are annual rates, must be adjusted. By assuming emissions are released at equal rates over the twelve month period, the data in Table 25 reflect the pollutants estimated to be emitted during the five month season of lawn and garden implement use (5/12ths of yearly emission rates).

Emissions from lawn and garden implements do not appear to have a significant impact on air pollution in this AQCR. Although they

```
SEASON    1974

      ESTIMATED IMPLEMENT POPULATION :

   2 STROKE WALK BEHIND MOWERS             41574.

   4 STROKE WALK BEHIND MOWERS            789900.

WALK BEHIND LAWN MOWERS                   831474.

RIDING MOWERS & GARDEN TRACTORS           148815.

MOTOR TILLERS                              70864.



                                         EXHAUST EMISSIONS  (TONS PER SEASON)

                                            HC           CO           NOX


  2-S WALK BEHIND LAWN MOWERS              1064.        2416.           8.

  4-S WALK BEHIND LAWN MOWERS              1937.       27869.         410.

WALK BEHIND MOWERS                         3001.       30285.         418.

RIDING MOWERS & GARDEN TRACTORS            1310.       18848.         277.

MOTOR TILLERS                               224.        3226.          47.


TOTAL LAWN & GARDEN IMPLEMENTS             4535.       52360.         743.


SEASON LENGTH =   5.0  MONTHS
```

Fig. 13. Sample output of lawn and garden implement computer program

FIGURE 14

PROJECTED LAWN & GARDEN IMPLEMENT EMISSIONS : HC

METROPOLITAN DETROIT-PORT HURON AQCR

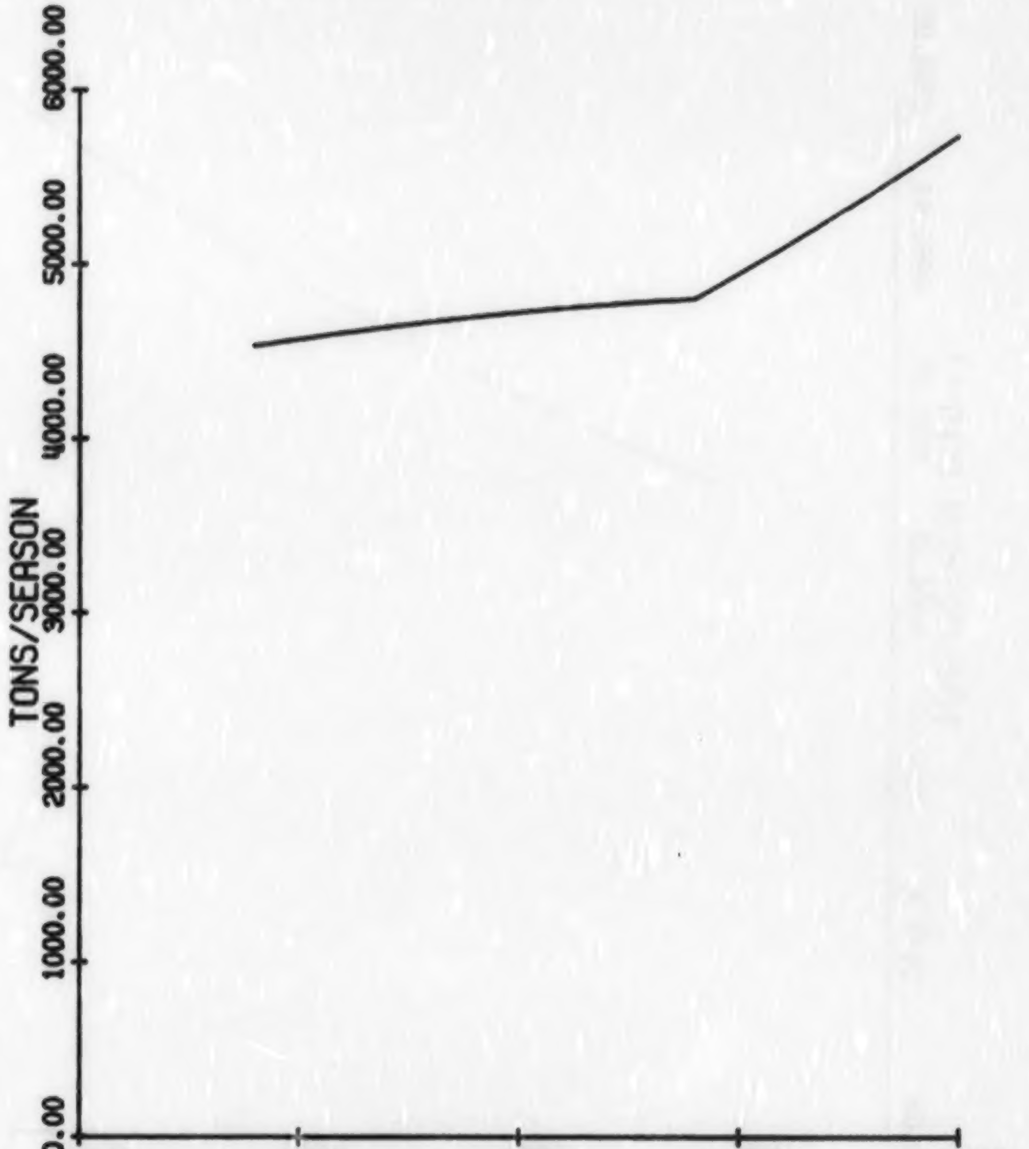


FIGURE 15

PROJECTED LAWN & GARDEN IMPLEMENT EMISSIONS : CO

METROPOLITAN DETROIT-PORT HURON AQCR

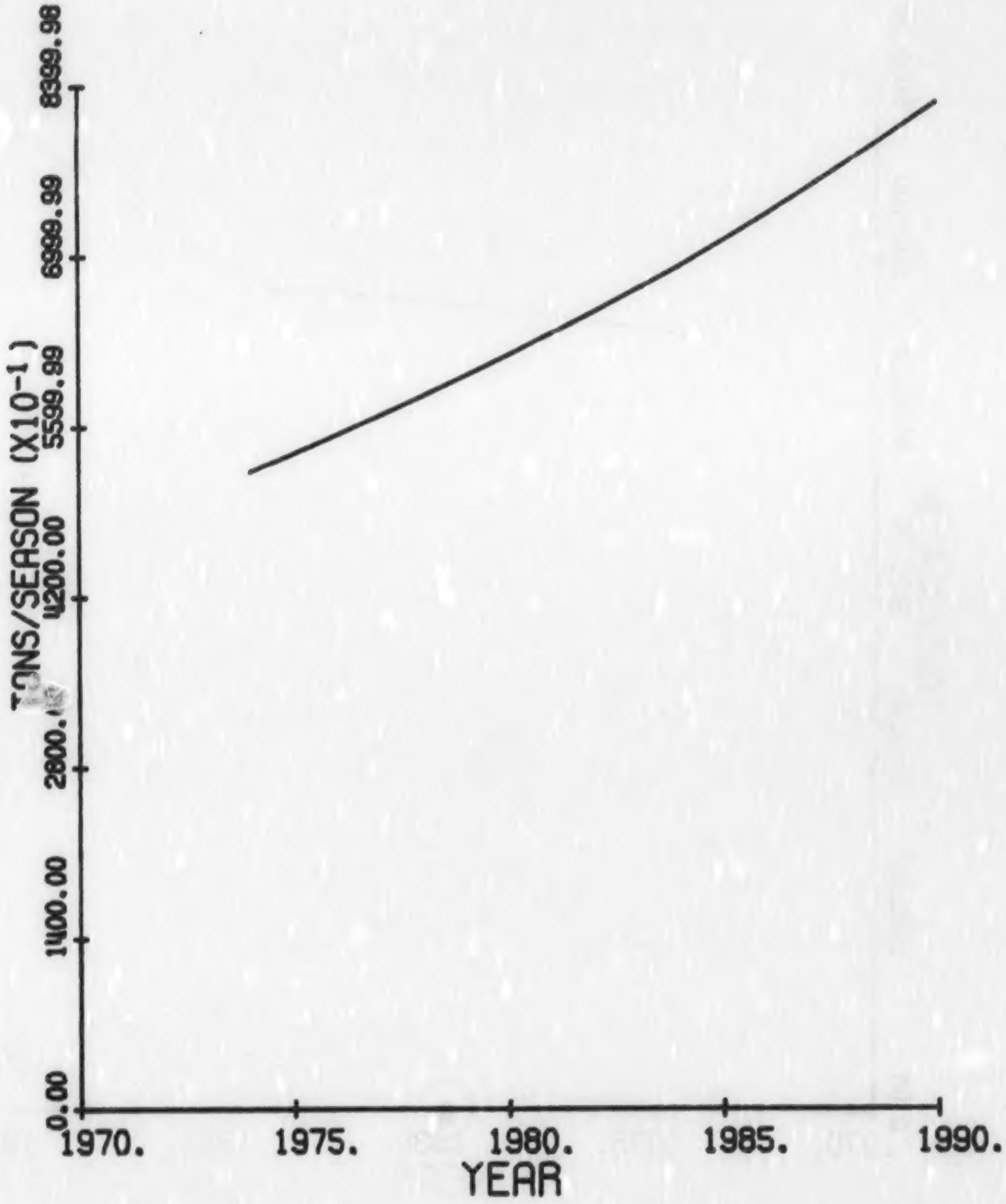


TABLE 25

EMISSIONS INVENTORY FOR THE METROPOLITAN DETROIT-PORT HURON AQCR, 1975 SEASON

Source	Tons per Season *		
	HC	CO	NO_x
Lawn & Garden Implements	4,572	53,833	766
Light Duty Vehicles	82,682	534,435	46,838
Heavy Duty Vehicles	17,283	103,675	4,962
Aircraft	2,907	6,701	1,611
Gasoline Handling Evap. Loss	8,873	--	--
Industrial Processes	12,168	820,005	4,764
Electric Generation	942	2,944	70,841
Fuel Combustion (Indust., Resid., and Commercial)	2,353	6,341	31,615
Solid Waste Disposal	5,323	12,187	866
Miscellaneous	13,485	845	33
Total Emissions	150,588	1,540,966	162,296
Lawn & Garden Implements as % of Total Emissions	3.0	3.5	0.5

* Season length is 5 months.

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

emit a sizeable quantity of carbon monoxide, it does not compare with industrial or automobile emissions. Lawn and garden implements could be a significant source of pollution, however, in areas with large human populations and few industrial sources, such as suburban areas. The computer program can be used to make quick, accurate estimates of implement emissions, and users should consider analyzing areas smaller than Air Quality Control Regions, for example, individual counties.

Figures 14 and 15 illustrate the projected emission trends of HC and CO from lawn and garden implements. The bend in the HC curve is a result of the phase out of lawn mowers powered by 2-stroke engines. Hydrocarbon emission factors of 2-strokes are an order of magnitude greater then those of 4-stroke engines (see Table 23). Thus, prior to their exclusion in 1984, their presence caused HC emissions to be greater than would have been the case had all implements been powered by 4-stroke engines.

PART 5

SNOWMOBILES

The increase in snowmobile popularity in the past decade has been phenomenal. From sales of less than 100,000 in 1968, they skyrocketed to 450,000 by 1973 [1]. Today there are well over one million snowmobiles in use during the winter months. The majority of them are concentrated in four northern states: Michigan, Minnesota, Wisconsin, and New York. Probably as a result of their rapid growth, snowmobiles have been subjected to close scrutiny by persons concerned with the protection of the natural environment. Engine noise is the most common complaint, but the snowmobile has also been accused of wildlife harrassment and the destruction of low-growing and young foliage. Only limited attention has been given to the role of snowmobiles in air pollution [2,3]. But snowmobiles are predominantly powered by 2-stroke gasoline engines which have less efficient combustion than 4-stroke engines. Also, their use can be very great in areas of abundant snowfall; in many smaller northern towns they often become the primary method of transportation in winter. For these reasons a study of snowmobile exhaust emissions on a regional level is necessary.

Snowmobile engines range from about 250 cm^3 to 500 cm^3 displacement with some larger engines available on high performance models. The majority have 2 cylinders and are air-cooled. In the past few years some snowmobiles have been produced with rotary engines, but the vast majority continue to be 2-stroke and this analysis concentrates exclusively on the latter.

Estimation of Emissions in a Selected AQCR

The method used to estimate exhaust emissions from snowmobiles requires the following:

1. Hours of snowmobile operation in the AQCR (hours per season)
2. Emission factors weighted by average engine displacement (grams of pollutant per hour)

The following sections describe the procedures used to obtain these factors. As is discussed in the next section snowmobile usage in an AQCR is not simply dependent on the number of machines owned by residents of the region. But for the initial selection of an AQCR, it is the deciding factor. Snowmobile registrations by county were obtained for the three top snowmobile states: Michigan, Minnesota, and Wisconsin [4,5,6]. Totals were calculated for AQCR's in these states and the Central Michigan Air Quality Control Region shows the greatest number of registrations: approximately 185,000 in 1974 (about 40% of Michigan's total). This region is selected for the snowmobile analysis.

The Central Michigan AQCR is very large covering 17,873 square miles, with a 1970 population of 2.2 million people. It includes the entire central area of Michigan's lower peninsula in the following counties:

Allegan
Arenac
Bay
Clare
Genessee
Gladwin
Gratiot
Huron
Ionia
Iosco
Isabella
Kent
Lake
Lapeer
Mason
Mecosta
Midland
Montcalm
Muskegon
Newaygo
Oceana
Ogemaw
Osceola
Ottawa
Roscommon
Saginaw
Sanilac
Shiawassee
Tuscola

Excellent data are available for snowmobile activity during the 1973-74 season, so this is chosen as the base season. The length of the snowmobile season is somewhat more variable than, say, those of boats or lawn and garden equipment. Mid-winter thaws are not uncommon in this region, but neither are heavy snowfalls in late November or late March. The State of Michigan recommends that snowmobiles be operated on snow at least four inches deep [7]. The length of a normal season is taken to be mid-December to mid-March (3 months).

Hours of Operation in the AQCR

The procedure used to estimate emissions from most of the other categories in this report starts with the category population in the AQCR. Next the average annual usage of a single unit is determined. By multiplying the population times the average usage the total hours of operation in the region is known. This method cannot be used for snowmobiles, however. Snowmobile activity in an area is not simply a function only of the number of machines owned by the residents. Over 65% of snowmobile owners have trailers, with the average snowmobile being trailered almost 900 miles every season [8,9]. A remarkable number of studies and surveys have been undertaken to determine the average usage of a snowmobile. The results have been less than consistent, ranging from 60 to 180 hours per season [8-13]. Of course, usage depends primarily on the weather conditions. The important point is not only how often the average snowmobile is used, but where it is used. If snowmobile activity is analyzed on a regional basis, the hours of use by non-resident snowmobilers must be considered.

In 1970 a survey of snowmobilers in Michigan determined that almost 30% of machine use is outside the county of residence [14]. And the percentage was much greater for residents of densely populated counties.

A similar but much more extensive survey was conducted by Gogebic Community College, Ironwood, Michigan for the Departments of Natural Resources of Michigan, Minnesota, and Wisconsin. The Three State Snowmobiler Economic and Preference Survey presents results of a questionnaire mailed to 19,000 snowmobile owners in the three states (approximately 5000 were returned and usable) [15]. The states were divided into areas (which in many cases are directly relatable to Air Quality Control Regions) and projections were made from actual responses. The survey reflects snowmobile activity in the 1973-74 season.

The data which are most useful to an emissions analysis concern the origin and destination of snowmobile trips. Respondents were asked to list the number of days they used their machines in each survey area. The answers were compiled to indicate the number of user-days in each area by residents and non-residents. The Central Michigan AQCR is made up of four of the survey areas. The AQCR covers such a large portion of the state that residents could literally travel hundreds of miles to use their snowmobiles and still be within its boundaries. Therefore, it is decided to count a user-day as being "non-resident" if it refers to a day of snowmobile use in one of the four survey areas by a non-resident of that area. The user may or may not be a resident of the AQCR. Table 26 lists the snowmobile user-days for the Central Michigan AQCR.

The data show that almost one-fourth of the snowmobile days were accumulated by non-residents, proving the high rate of snowmobile trailering.

A user-day is defined in the Three State Survey as as "a day on which you use your snowmobile". This is not very specific. The snowmobile could have been used for 15 minutes or 15 hours. Since the emissions are based on hours of engine operation, it is necessary to relate the number of user-days to actual hours of use. The assumption can be made that if the snowmobile is used in a place that is not to close the user's home it will be operated for a longer period. In other words, if the snowmobile is trailered to its place of use, the chances are that the primary purpose of the trip is going snowmobiling.

In another survey 45% of snowmobile owners said they had made an overnight trip during the season for the purpose of snowmobiling [8]. On the other hand, use of the snowmobile around home is expected to be more frequent but of less duration. Thus, the following assumptions are made:

1. The average hours of snowmobile use for a resident user-day is 2.5 hours
2. The average hours of snowmobile use for a non-resident user-day is 6.0 hours

TABLE 26

DAYS OF SNOWMOBILE USE IN THE CENTRAL MICHIGAN AQCR, 1973-74 SEASON

	Snowmobile User-days
Residents	3,262,400
Non-residents	947,300
Total	4,209,700

These estimates may seem high, but by applying them to the user-days accumulated by residents of the Central Michigan AQCR in 1973-74 and dividing by the total number of snowmobiles registered there, the average usage is found to be about 70 hours per season. This is lower than the usage estimates from a number of other sources.

Using the above assumptions and the data from Table 26 the total hours of snowmobile activity in the Central Michigan AQCR during the 1973-74 season is calculated as shown in Table 27.

This represents a substantial amount of snowmobile operation. It must be remembered, however, that this region is very large and many of the non-resident snowmobilers come from the metropolitan Detroit area. It should also be noted that these figures apply only to registered snowmobiles. One estimate puts the number of unregistered machines as 8% of the total population [8]. In Michigan a snowmobile need not be registered if it is used exclusively on the owner's property. Another point is that the hours of use refer to hours of engine operation, not just when the vehicle is in motion. Some snowmobiles are difficult to start so users commonly leave them idling for extended periods. A final note is that the winter of 1973-74 was the most intense period of the recent "fuel crisis". There is no doubt that, were it not for this, snowmobile activity would have been even greater.

TABLE 27

HOURS OF SNOWMOBILE USE IN THE CENTRAL MICHIGAN AQCR, 1973-74 SEASON

	Estimated Hours of Snowmobile Use
Residents	8,156,000
Non-residents	5,684,000
Total	13,840,000

Emission Factors

The data on which emission factors are based come from tests done by Southwest Research Institute for the U.S. Environmental Protection

Agency [2]. Emissions were measured from three snowmobile engines. (A rotary engine was also tested but was not included in composite emission factor calculations because of their limited use in snowmobiles.)

The horsepower of a snowmobile is rarely referred to; engine size is designated by its displacement in cubic centimeters. Emission factors for snowmobile engines are grams of pollutant per hour weighted to reflect the average displacement of the total snowmobile population.

The duty cycle upon which SWRI weighted the individual mode emissions is taken from very limited snowmobile operating data. The limitations are fully discussed in the SWRI report and, until more representative data are available, there are no alternatives. The average load factor which results from the assumed duty cycle is 0.22.

The average engine displacement used by SWRI in their calculations is 362 cm^3. This was derived to represent the 1971-72 snowmobile population. More recent data have been published since then. The International Snowmobile Industry Association states that the growth of average engine size has leveled off in the past few years [16]. The ISIA annual statistics for 1972-73 show the average displacement of a U.S. snowmobile to be 369 cm^3 [17]. The emission factors used in the following analysis are the SWRI results adjusted to an average engine size of 369 cm^3. They are listed in Table 28.

Base Year Emissions

The parameters described above are used to estimate emissions from snowmobiles in the Central Michigan Air Quality Control Region. The equation is:

(Hours of snowmobile operation in AQCR)
x (Grams of pollutant/hour) x (Unit conversion factor)
= Tons of pollutant/season

TABLE 28

SNOWMOBILE EMISSION FACTORS

	Grams per Hour
HC	642.
CO	996.
NO_x	10.2

TABLE 29

EMISSIONS FROM SNOWMOBILES IN THE CENTRAL MICHIGAN AQCR, 1973-74 SEASON

	Tons per Season		
	HC	CO	NO_x
Residents	5,770	8,950	92
Non-residents	4,020	6,240	64
Total	9,790	15,190	156

Table 29 lists the estimated exhaust emissions from resident and non-resident snowmobiles for the 1973-74 season.

Projected Growth Analysis

The major parameter in the calculation of snowmobile emissions is "hours of operation in the AQCR". To project the growth of this parameter, the growth of the snowmobile population is analyzed. Accurate counts of national population are not kept, so the yearly increase of snowmobile registrations in Michigan will be considered typical.

Registration statistics from 1971 to early 1976 show an interesting growth pattern. The annual increase has been declining from a phenomenal 53% increase between 1971 and 1972 to about 2% between 1975 and 1976. Obviously the market has peaked and is stablizing into a steady growth. The International Snowmobile Industry Association confirms that the fuel shortage of 1973-74 had a major effect on snowmobile sales [1]. A recreational industry such as snowmobiling will continue to be strongly influenced by consumer attitudes regarding fuel availability and cost. Barring any unforeseen fuel shortages, the interest in snowmobiling can be expected to regain some if its former momentum. ISIA estimates that future sales will increase 5% a year. As the snowmobile market stabilizes, the percentage of sales that represent new growth, as opposed to replacement, will approach a constant. Considering ISIA's 5% a year estimated sales growth, and realizing they have an understandably optimistic viewpoint, the snowmobile population in Michigan (and in the U.S.) is projected to have a growth rate of 4.0% per year through 1990. Other environmental concerns, particularily noise, must be dealt with by snowmobile manufacturers. Their efforts, along with those of snowmobile owners and government agencies in providing adequate snowmobiling areas, will determine to a great extent the actual growth of this relatively new winter sport in the coming years.

Predictive Computer Program

The computer program which can be used to estimate seasonal emissions from snowmobiles in an Air Quality Control Region for any year between 1974 and 1990 is listed in Appendix 5. Emission factors and the average engine displacement on which they are based are assumed to remain constant through the years. The input parameters are 1) length of snowmobile season (th[illegible] parameter is not actually used in the calculations), and 2) projected growth rate of the snowmobile population in the AQCR. The growth rate is a constant annual increase, compounded yearly.

As discussed in a preceeding section, snowmobile activity in an AQCR is not exclusively a function of snowmobile registrations. Many owners transport their machines on trailers in search of open areas suitable for riding. An indicator parameter must be developed to allow for an estimation of snowmobile activity in a region from related county information. Fortunately, extensive data are available on snowmobile activity in three major northern states. The Three State Snowmobile Survey described previously permits compilation of total hours of snowmobile activity in AQCR's in Michigan, Minnesota and Wisconsin. The areas into which the survey divided the states does not always correspond to AQCR boundaries, but with some slight adjustments, data for eleven AQCR's are obtained. These AQCR's include large metropolitan areas (Detroit, Minneapolis-St. Paul), as well as sparsely populated areas (northern Michigan and Minnesota). The same assumptions are made concerning a snowmobile user-day as in the preceding analysis: a resident user-day is equivalent to 2.5 hours of snowmobile operation, and a non-resident user-day is equivalent to 6.0 hours of operation.

The data now consists of total hours of snowmobile operation in each of eleven AQCR's for the 1973-74 season. The next step is to gather other AQCR parameters which may influence use of snowmobiles. Snowmobile registrations, land area, human population, and density were compiled for each AQCR [4,5,6,18]. A multiple linear regression analysis was performed for the eleven regions on the dependent variable "total hours of snowmobile use". The independent variables which show the strongest regression are 1) snowmobile registrations, and 2) human density. The multiple correlation coefficient shows significance at the 99% level ($r^2=0.843$) for the following equation:

$$\text{Total hours of snowmobile use} = 58.5\,(\text{registrations}) - 7{,}190.\,(\text{density}) + 4.95 \times 10^6$$

where density equals human population in the AQCR per square mile.

Qualitatively this says that snowmobile activity in a region is directly proportional to the number of snowmobiles registered, and inversely proportional to the density of the human population. In densely populated areas there is little open area on which to operate a snowmobile.

The computer program utilizes this regression equation to estimate snowmobile activity in an AQCR. The density factor uses 1970 census data and is most readily obtained for counties from the 1972 County and City Data Book [18]. Snowmobile registrations by county are available from appropriate state agencies. The program does not separate total snowmobile activity into resident and non-resident use. In the growth analysis routine the only parameter affected is snowmobile registrations; AQCR density is assumed to remain constant.

To summarize, the input data and indicator parameters which must be supplied by the user are:

1. Snowmobile registrations in AQCR
2. Human density of AQCR, in persons per square mile
3. Length of snowmobile season, in months
4. Projected growth rate of snowmobile registrations in AQCR, in percent increase per year

A complete description of the required format for the input data is included in Appendix 5.

Figure 16 is a sample of the printed computer output. Estimated total snowmobile seasonal use in the AQCR is listed, as well as corresponding exhaust emissions. The estimates are for the Central Michigan AQCR, 1973-74 season. Note that there is a difference between these figures and the emissions shown in Table 29. The regression equation predicts about one million hours more for the Central Michigan AQCR than that calculated in the preceeding analysis. This is because the equation gives the best fit for all data, thus, at any given data point the predicted value will not exactly equal the actual value. Emissions listed in Table 29 should be considered the better estimate.

Figures 17 and 18 plot the trends of the two most prominent snowmobile pollutants, HC and CO, over the time period 1974 and 1990. They reflect the projected 4.0% annual snowmobile growth rate.

Comparison with Other Air Pollution Sources

Table 30 lists the emissions inventory of the Central Michigan Air Quality Control Region for the three winter months of 1974-75. Snowmobile emissions are as predicted by the computer program, and other source emissions are from the National Emissions Data System as of June, 1975 [19]. Since the use of snowmobiles is seasonal, the NEDS data, which are annual rates, must be adjusted. By assuming emissions are released at equal rates over the twelve month period, the data in Table 30 reflect the pollutants estimated to be emitted during the three month snowmobile season (one-fourth of yearly emission rates).

The data show that hydrocarbon emissions from snowmobiles contribute nearly 20% of the total HC emitted in this region during the winter months. They are second only to light duty vehicle emissions in regard to this pollutant. On a mass basis snowmobiles emit more

Reproduced from best available copy.

```
SEASON   1973 - 1974


ESTIMATED HOURS OF SNOWMOBILE USE : 14907528.



EXHAUST EMISSIONS  (TONS PER SEASON)

          HC                 10550.

          CO                 16367.

          NOX                  15[illegible].



SEASON LENGTH =   3.0  MONTHS
```

Fig. 16. Sample output of snowmobile computer program

FIGURE 17

PROJECTED SNOWMOBILE EMISSIONS : HC

CENTRAL MICHIGAN AQCR

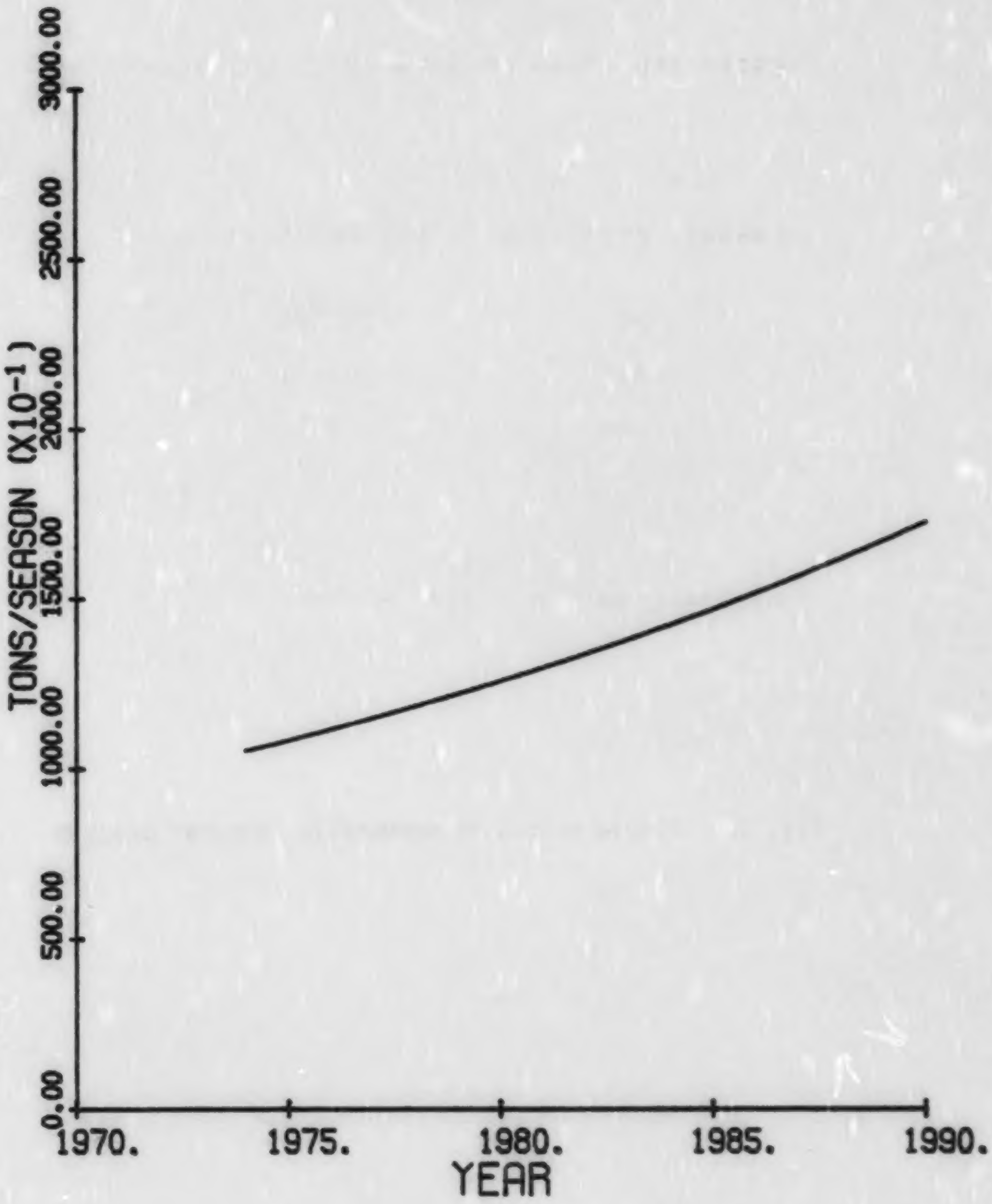


FIGURE 18

PROJECTED SNOWMOBILE EMISSIONS : CO

CENTRAL MICHIGAN AQCR

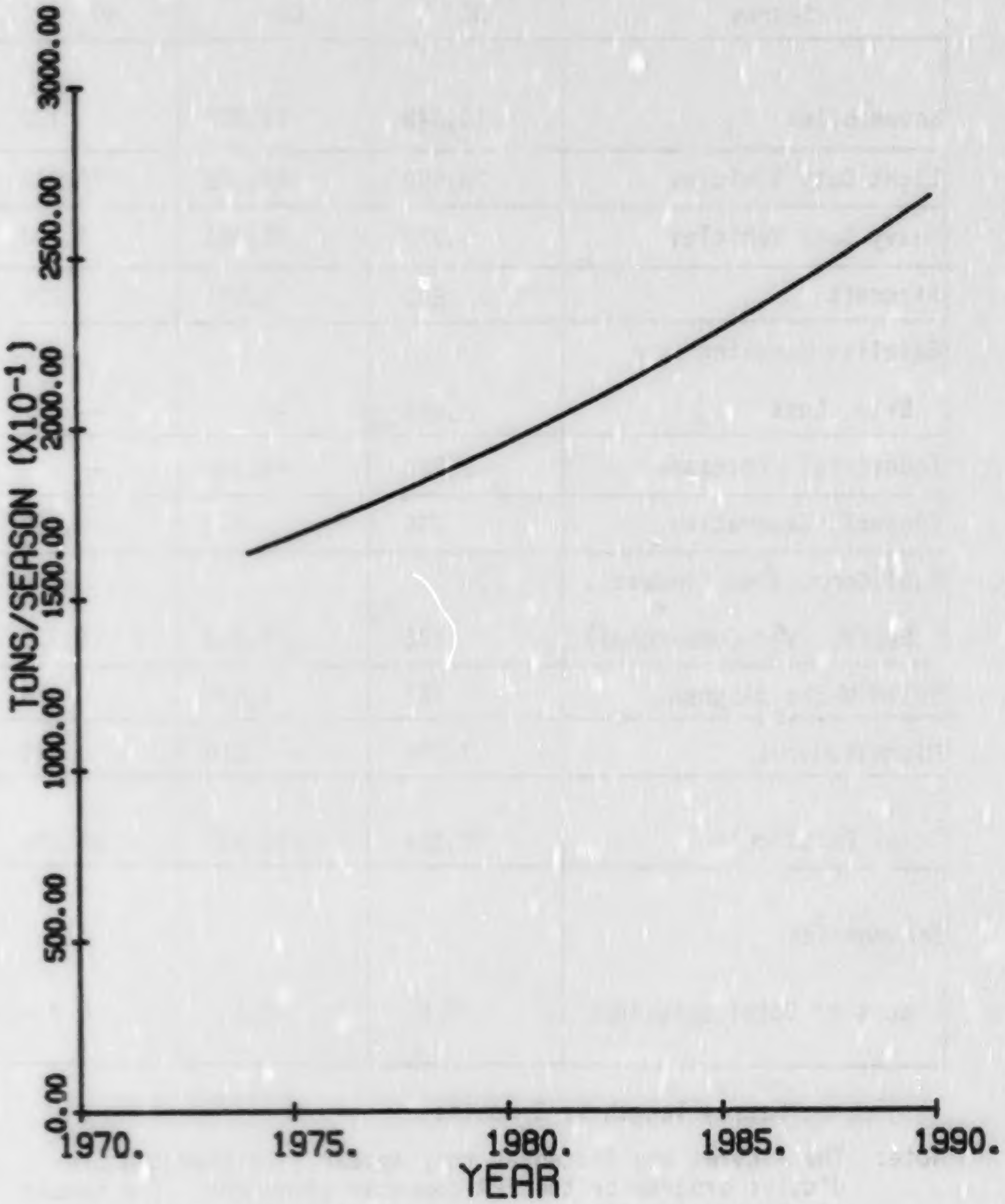


TABLE 30

EMISSIONS INVENTORY FOR THE CENTRAL MICHIGAN AQCR, 1974-75 SEASON

Source	Tons per Season*		
	HC	CO	NO_x
Snowmobiles	10,848	16,829	172
Light Duty Vehicles	28,693	169,672	18,912
Heavy Duty Vehicles	6,019	33,063	4,406
Aircraft	840	1,576	276
Gasoline Handling Evap. Loss	2,853	--	--
Industrial Processes	2,224	44,340	--
Electric Generation	238	862	16,982
Fuel Combustion (Indust., Resid., and Commercial)	722	1,669	14,378
Solid Waste Disposal	921	2,636	155
Miscellaneous	3,966	270	10
Total Emissions	57,324	270,917	55,291
Snowmobiles as % of Total Emissions	18.9	6.2	0.3

*Season length is 3 months

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

CO than HC, but so do most other sources. In terms of the percentage of total emissions snowmobiles account for about 6% of the carbon monoxide.

Even though this area of Michigan experiences intense snowmobile activity, it is surprising that the resulting emissions are so high. Of course, snowmobiles use 2-stroke engines because of their greater power-to-weight ratio, and these engines are considerably "dirtier" than comparable engines operating on a 4-stroke cycle. It is also possible, however, that the NEDS emission data are incomplete for this AQCR. It seems particularly suspect in the case of emissions caused by industrial processes; for example, no NO_x emissions are listed. This seems questionable since the region encompasses the industrilized cities of Flint, Grand Rapids, and Saginaw.

But even if snowmobiles are not as significant a polluter in this AQCR, it is certain that their contribution is not negligible during the months of their operation. The computer program which has been developed provides an excellent tool for monitoring snowmobile emissions in any area of their use. It can be especially useful when applied to areas of smaller size than Air Quality Control Regions, such as individual counties.

PART 6

OUTBOARD MOTORS

Boating is one of the largest recreational activities in the United States. At the present time Americans use their nearly 10 million recreational boats for fishing, hunting, water skiing, or simply pleasure cruising. Over half of these boats are powered by outboard motors, of which there are over 7 million in use [1]. Virtually all outboard motors are 2-stroke gasoline engines, which are known to emit a greater amount of carbon monoxide and unburned hydrocarbons than would a similar engine operating on a 4-stroke cycle. Furthermore, their use may be highly localized, and in northern climates may be very intense over the short boating season.

These reasons justify a thorough analysis of air pollution caused by outboard motors. This Part studies gaseous outboard motor exhaust emitted into the atmosphere in a region considered to have a large amount of boating activity. Originally, this category was to have included all power boats: outboards, inboards, and inboard/outdrives. The latter two engine types were deleted due to their relatively small numbers (only about 10% of all power boats). Also, whereas all outboards are of a similar engine type, inboards may be gasoline or diesel, 2 or 4-stroke, carbureted or injected, etc.. And there is very little information about typical emissions, duty cycles, or usage of inboard engines.

Emissions from outboard motors are unique in that the exhaust is released into the water. Thus, a certain amount of "scrubbing" is done on the gaseous emissions before they are released to the atmosphere. Certain amounts may remain in the water phase. A further complication is the effects of crankcase drainage. It is the nature of a 2-stroke engine that oil be mixed with the gasoline for lubrication. Some of this gas/oil mixture condenses in the crankcase. All engines manufactured since 1972 have re-circulation systems, but prior to that in some engines this crankcase drainage (condensate and vapor) was simply introduced into the exhaust stream where it was released with the gaseous exhaust into the water.

These factors make the estimation of emissions from outboard motors very difficult, and they are discussed in more detail in the section on emission factors. The important point to be made is that this analysis deals only with outboard motor emissions which end up in the atmosphere. A sizable amount of research has been conducted on the effects of outboard motor exhaust on the aquatic environment and no attempt is made to investigate that issue.

Estimation of Emissions in a Selected AQCR

At first consideration the choice of an Air Quality Control Region with a high degree of boating activity would seem to be limited to the southern part of the country where warm weather permits year round use. But statistics of boat ownership show that the northern states of Michigan, Minnesota, and New York are in the top five ranked according to number of boats registered [2]. Also, data on the frequency of use seem to indicate that even with relatively short seasons boaters in northern states use their craft almost as much as year round boaters [3].

Thus, it is decided to choose the Detroit-Port Huron Air Quality Control Region for analysis. (This region was also chosen for the analysis of lawn and garden implements and its boundaries are described in that Part). The region includes the Detroit River, Lake St. Clair, and the St. Clair River, all major boating waters, as well as numerous inland lakes. The base year of the emission analysis is 1974. In this part of the country the boating season runs from about mid-May to mid-September. The most intense usage occurs between the "summer bookend" holidays of Memorial Day and Labor Day, but enthusiasts can stretch the season to five or even six months. The season length for this study is four months.

The parameters that are needed to estimate emissions from outboard motors are:

1. Outboard motor population in the AQCR
2. Average usage (hours per season)
3. Average engine size (horsepower)
4. Emission factors (grams of pollutant per rated horsepower-hr)

Outboard Motor Population in the AQCR

The obvious starting point for a determination of the number of outboard motors in an area is boat registration statistics. The Federal

Boat Safety Act of 1971 gives states the right to register boats in their waters. Not all states have similar numbering systems. As of December 31, 1975, forty states number all motorboats regardless of horsepower [1]. In Michigan all boats 12 feet or greater in length must be registered only if they will be used with a motor [4]. In effect this includes nearly all watercraft.

Statistics on registered boats cannot be considered to equal the number of outboard motors. Some boats are manual or wind powered; some have inboard engines. Also, there are people who own outboard motors without owning a boat. These motors, usually low horsepower, are most often used on rented or borrowed boats. But registrations are the only data available that are related to regional boating activity. If the total U.S. population of outboard motors could be determined, then the following ratio can be used to estimate outboard population in an AQCR.

$$\frac{\text{Outboard population in AQCR}}{\text{Outboard population in U.S.}} = \frac{\text{Registered boats in AQCR}}{\text{Registered boats in U.S.}}$$

This proportionality assumes a direct relationship between the number of all types of boats in a region and the number of outboard motors used in that region. A study conducted by the U.S. Coast Guard in 1974 gives evidence that the assumption is credible. A nationwide survey of randomly selected households was taken to gather information about recreational boating. Households containing boat owners or boat operators were asked about the type of boat owned or operated, its length, age, horsepower, boating exposure (usage), accident information, etc.. Results are tabulated for the total United States, and for seven regions (Great Lakes, New England, Mid-Atlantic, Gulf Coast, etc). Discussing regional distribution by boat types the report states: "The outboard motorboat is not only the most populous boat type, but also seems to be the one homogeneous type of boat. No one region seems to have a proportionately unusual number of outboards" [3].

Thus, the above equation can be considered the most reliable means of estimating AQCR outboard population utilizing the available information. Boat registration records by county in Michigan are kept by the Secretary of State. Registrations are valid for three years so a count for 1974 is not exact, but is as accurate as possible. The four counties in the Detroit-Port Huron AQCR were found to have 174,000 registered boats in 1974. This is 29% of the state total [4]. The total number of boats registered in the U.S. on December 31, 1974, was 6,830,500 [1].

The third factor in the equation is national population of outboard motors. The National Association of Engine and Boat Manufacturers publishes extensive information on annual sales of outboards. They also give an estimate of the current number of motors owned, and the 1974 national population estimate is 7,595,000 outboard motors [1]. The accuracy of this estimate can be substantiated by using methods developed in similar research efforts which devised an equation for calculating surviving motors using an exponential retirement rate as a function of motor age [5,6]. The equation, applied to annual sales data, results in a 1974 "surviving" population exactly equal to the above figure. It is interesting to note that there are more outboard motors in use than registered boats. This is because, as mentioned, people own motors without also owning a boat. Also, results of the Coast Guard survey show about 3% of the outboard boats have two engines.

The three factors needed to calculate AQCR outboard population have now been determined. The proportionality equation results in an estimated 1974 outboard motor population of 194,000 for the Detroit-Port Huron AQCR.

Average Usage

The only available data related to usage of outboard motors come from the recent Coast Guard survey of boaters [3]. The results show that boats with outboard motors are used approximately 130 hours per year. This is not the same as motor usage, however. The motor is not operating at all times the boat is being used. A survey of boat buyers indicate that 40% said the primary use of the boat would be fishing, and 30% said hunting [7]. Both of these activities involve substantial boat use without the motor running. Most outboard motors require little effort in starting so boaters do not hesitate to shut them off when propulsion is not needed.

Both the Boating Industry Association and a major outboard engine manufacturer estimate that a typical motor is used about 50 hours per season [8,9]. This may be lower than the average usage by an outboard boat owner, but as stated, many motors are owned by nonboatowners. In the absense of any precise data the average annual usage of an outboard motor in the Detroit AQCR is estimated to be 50 hours of use over a four month season.

An important point to be discussed concerns the place of boat use versus the place of its registration. A boat owner most often registers the craft in the county of his/her residence. But the boat can be used anywhere. Certainly some boats are never used in the county of registration, others are trailered on vacations, to summer homes, etc.. Unfortunately, there is no way to adequately determine the total hours of boat (or more precisely, outboard motor) usage in a county or an AQCR over an entire season. The method used here, based on boat registrations, is an imperfect estimate, to be sure. But, in general, it is reasonable to expect that a region containing a large number of registered boats also has areas where those boats can be used. This is the case in the Detroit AQCR. Some of its resident boat owners use their craft outside the region, but non-resident boaters come to use its waters, particularly Canadians who share an aquatic boundary.

Average Engine Size

Sufficient data exist to determine the average rated horsepower of the outboard motor population. Annual motor sales by various horsepower classifications are regularly compiled [1]. The equation mentioned in the previous section, which predicts the fraction of surviving motors produced in a given year from their age, is used to tabulate the 1974 population by horsepower. By dividing the total horsepower of outboard motors by their population the average size is found to be 29.2 hp. This compares very well with the findings of the Coast Guard survey which lists the average craft horsepower of outboard boats as 30.0 hp. The latter figure does not account for motors owned without boats, which are generally low horsepower. Therefore, the average size of an outboard motor in 1974 is estimated to be 29.2 hp.

Emission Factors

Measurements of atmospheric emissions from outboard motors have been done in two previous research projects: one by Southwest Research Institute, and the other a joint effort by the Environmental and Water Resources Engineering Laboratory and the Automotive Engineering Laboratory of The University of Michigan.

In the SWRI study emissions were measured from four outboard motors with the following rated horsepowers: 4, 9.5, 35 (each with 2 cylinders), and 65 hp (4 cylinder) [5]. The tests were performed in a laboratory which meant the procedures had to simulate, as nearly as possible, actual load conditions the motors would experience while propelling a hull through water. Load is determined by the drag characteristics of the hull and engine combination. It is generally agreed that the planing hull of a pleasure boat follows a exponential load equation of 2.5 order. The order is near 3.0 for low speed operation. SWRI simulated load conditions of 2.5 for the three larger engines, and 3.0 for the small horsepower engine.

Briefly, SWRI used the following test procedure. The outboard motor was connected to a dynamometer at the propeller shaft. The shaft was not in water. Rather, all the raw exhaust gas was sampled and measured. Then the gas was passed through a bubbling tank of water and measured again. The difference between before and after bubbling was supposed to simulate the water scrubbing effects of actual operation, since the exhaust is exited directly into the water near the propeller. From these measurements SWRI developed emission factors for atmospheric and water phase emissions.

The tests done at The University of Michigan did not attempt to separate the fraction of emissions that would remain in the water and that which would pass into the atmosphere [10]. Total emissions were measured from twelve outboard motors using a laboratory procedure similar to that of SWRI. The Michigan test results compare favorably to those of SWRI in terms of mass emission rates. But the interesting findings concerned the evaporation of hydrocarbons from the receiving waters. This is the only pollutant which may be dissolved in any significant amount. Carbon monoxide has limited solubility in water, and emissions of oxides of nitrogen are extremely low from outboards. Whereas SWRI studied water scrubbing effects, that is , the amount of exhaust gas which was released instantaneously to the air, the Michigan study measured evaporation rates from exhaust-contaminated water over a period of hours and days.

Both studies determined that the amount of HC released to the atmosphere, whether instantaneously or over a long time period, depends on water turbulence. In actual operation outboard exhaust exits near the propeller, so there is extreme turbulence for a short time. The SWRI tests showed greater turbulence resulted in a greater amount of

HC remaining in solution. However, the Michigan tests show greater evaporation rates over long periods with increased turbulence. This means that in turbulent water even though more pollutant is initially condensed, it evaporates quicker.

This phenomenon also acts on crankcase drainage. As mentioned previously, some outboards manufactured prior to 1972 disposed of crankcase drainage (gasoline/oil condensate) by releasing it with the engine exhaust gases. The SWRI emission measurements did not include any possible effects of drainage. But this is primarily a water pollution problem, and has been analyzed in a separate research effort by SWRI for the Environmental Protection Agency [11].

The conclusions to be drawn from all this is that quantifying exhaust emissions from outboard motors is an extremely complex undertaking. The current studies, SWRI and Michigan, provide valuable information as to the impact of outboard motors on both the atmospheric and aquatic environments. The analysis which follows describes the development of emission factors which are used to estimate atmospheric emissions of outboard motors. They are based on data from the SWRI tests which can be considered the most appropriate. If anything, the results of these tests are conservative because, as the Michigan tests show, some of the hydrocarbons that condense in the water on contact eventually evaporate into the atmosphere.

Emission factors for outboard motors, in grams of pollutant per horsepower-hour, are derived in a manner differing from that used in most of the other categories in this report. Rather than estimating an average engine load factor to represent all outboard motors, emissions from each of SWRI's test engines are weighted according to that engines individual load characteristics, which in turn are a function of the chosen boat/motor combination (planing or displacement hull operation). Essentially, the emission factors are calculated by the method described in the SWRI report, the only difference being that more recent engine operating data are used to weight the raw exhaust emissions.

The first step is to determine duty cycles of typical outboard motors. SWRI used data developed by Outboard Marine Corporation, manufacturers of Johnson and Evinrude motors, from boat load and usage surveys in 1971 and 1972. These surveys monitored the percentage of engine operating time in various rpm ranges. Because engines of different size (hp) exhibit different operating profiles, the data are grouped into four horsepower classifications. Eleven boats were monitored for a total of about 200 hours. But the horsepower of the test engines does not appear to be distributed in a manner consistent with outboard population. There are seven engines of high horsepower, and none in the most common range: 10 to 35 hp. Furthermore, the boat which accumulated approximately one-fourth of the total test hours is an 18 foot craft with a 100 hp engine, which can hardly be considered typical. This explains the heavy weighting of the duty cycle toward high rpm ranges.

More recent and, presumably, more typical engine operating data were gathered in 1973 by OMC for the Boating Industry Association [12]. It represents about 170 hours of operation on 34 boats which are more evenly distributed over the horsepower range. OMC supplied these data emphasizing that it cannot be considered statistically significant. It is used here with full understanding of those qualifications.

Table 31 lists the OMC survey data compiled in four horsepower categories. The data show that, on the average, outboard motors operate less than 10% of the time above 90% of maximum rpm. All engines, except the very small, operate a surprisingly large amount of time at very low rpm's.

By assuming typical maximum engine rpm's for each horsepower category (4500,4700,4900,5000, respectively for increasing hp), these data are used to derive weighting factors for the individual modes used by SWRI in the emission tests. As stated, SWRI measured emissions from four engines: 4, 9.5, 35, and 65 hp. The weighting factors of the "less than 10 hp" class are applied to the 4 and 9.5 hp engines; those of the "11 to 44 hp" class to the 35 hp engine; and a combination of the "45 to 65 hp" and "greater than 65 hp" classes are used for the 65 hp engine. Individual mode mass emissions (g/hour) are weighted for each engine. The resulting composite mass emissions are listed in Table 32 .

The next step in determining brake specific emission factors is the calculation of individual engine composite horsepower outputs. These are derived by weighting the horsepower developed in each mode as given in the SWRI report. By dividing the mass emissions in Table 32 by the horsepower outputs, individual engine brake specific emission factors are obtained (g/hp-hr).

The final step is weighting each engine's emission factors in a manner which represents that engine's prevalence in the total outboard

TABLE 31

TYPICAL OUTBOARD MOTOR DUTY CYCLES FOR FOUR HORSEPOWER CATEGORIES *

Percent of Max RPM	Percent of Time Spent in Each Mode			
	Less than 10 hp	11-44 hp	45-65 hp	Greater than 65 hp
5	1	19	7	26
15	6	14	18	16
25	22	11	10	8
35	34	8	8	7
45	5	6	8	7
55	2	19	8	10
65	3	8	12	8
75	4	3	9	8
85	18	6	13	6
95	5	4	5	4

* Data from reference 12

TABLE 32

COMPOSITE MASS EMISSIONS OF FOUR OUTBOARD MOTORS

Engine	Grams per Hour		
	HC	CO	NO_x
OMC, 4 hp	140.	330.	0.56
OMC, 9.5 hp	335.	961.	1.24
Chrysler, 35 hp	787.	2,770.	1.60
Mercury, 65 hp	1,710.	3,630.	10.5

motor population. To do this each of the four test engines will represent a horsepower range of the population. The SWRI report contains a breakdown of the outboard motor population into four horsepower ranges. This breakdown (updated to 1974) is used to calculate the total horsepower available (or rated) in each range. By applying the load factors previously calculated, the total horsepower developed (or actually generated) is obtained for each range. This factor:

$$\frac{\text{Total hp developed in hp range}}{\text{Total hp available in hp range}}$$

is used to compute a final weighted emission factor for each of the three pollutants. Table 33 lists each engine's emission factors, the horsepower weighting factors, and the final population emission factors. It must be remembered that these factors are subject to all the qualifications and assumptions discussed above. But they can be considered as the best possible estimates using all the currently available information on outboard motors.

Base Year Emissions

The equation used to calculate seasonal mass emissions of outboard motors differs from those used in other categories in that the emission factors already include the load factor weighting. In effect the equation is:

TABLE 33

OUTBOARD MOTOR EMISSION FACTORS

Engine	Weighting Factor hp developed / hp rated	Engine Emission Factors (g/developed hp-hr)			Weighted Emission Factors (g/rated hp-hr)		
		HC	CO	NO_x	HC	CO	NO_x
OMC, 4 hp	0.0105	149.	350.	0.592	1.56	3.68	0.006
OMC, 9.5 hp	0.0343	133.	381.	0.490	4.55	13.0	0.017
Chrysler, 35 hp	0.0516	112.	395.	0.228	5.79	20.4	0.012
Mercury, 65 hp	0.138	109.	231.	0.671	15.0	31.8	0.092
					26.9	68.9	0.127

(Outboard population in AQCR) x (Avg hours of use/season)

x (Avg rated engine hp) x $\left[\sum \right.$(hp developed/hp rated)

x (Grams/hp-hr) $\left. \right]$ x (Unit conversion factor)

= Tons of pollutant/season

where the bracketed parameter is the emission factor calculated by summing the four individual test engine emission factors weighted by the appropriate load factor. Table 34 lists the estimated atmospheric emissions from outboard motors for the 1974 season in the the Detroit-Port Huron Air Quality Control Region.

TABLE 34

EMISSIONS FROM OUTBOARD MOTORS IN THE DETROIT-PORT HURON AQCR, 1974

Tons per Season*		
HC	CO	NO_x
8,370	21,500	40

* Season is mid-May to mid-September: 4 months

Projected Growth Analysis

The data used to estimate the future growth of outboard motors are from the annual publication of Marex and the National Association of Engine and Boat Manufacturers [1]. This lists an estimate of the number of gasoline outboard motors owned in the U.S.. The growth of outboard motors has been smooth and steady over the past 10 years. The rate of annual increase has consistently been between one and two percent. This shows that the outboard motor market is well established and can be expected to continue in this pattern.

As is the philosophy of this study, future growth rates are normally projected to be somewhat lower than those of previous years. This is based on the belief that the national economic climate will be slightly cooler over the next 10 to 15 years than it was in the late 1960's and early 70's. This, of course, is due in part to higher fuel cost which significantly affects a recreational industry such as boating. Thus, the growth rate of outboard motors is projected to be 0.9% per year. This will be assumed valid through 1990, and it is further assumed that outboards will remain predominantly 2-stroke gasoline engines.

Predictive Computer Program

Appendix 6 lists the computer program which can be used to estimate mass emissions of outboard motors in any Air Quality Control Region in the country for any year from 1974 through 1990. Emission factors and average rated horsepower are assumed to be constants regardless of individual AQCR characteristics. And even though the average horsepower of motors sold has jumped from 35 to 40 hp between 1971 and 1974, it seems unlikely that this trend will continue. Input parameters for the category are 1) length of boating season, and 2) projected growth rate of the outboard motor population in the AQCR.

Depending on the user's input, the program assigns one of two usage rates. If the boating season is stated to be less than or equal to six months, usage is assigned as 50 hours per season. If greater than six months, usage is 75 hours per season. This may appear to give unequal weighting to regions with long boating seasons, but all available data indicate that boat use is not proportional to season length. A Coast Guard survey of recreational boaters shows little difference between usage by boaters in the Great Lakes area and usage by all U.S. boaters [3]. In other words, boat use is very intense during a short season, and much less intense over a long season, so that the total hours of use is not greatly different. The above figures are chosen due to the lack of more precise information.

As discussed in a preceding section, an indicator parameter of outboard motor population in a AQCR is boat registration statistics. The main precept of this method, that outboard motors in an AQCR are proportional to the number of registered boats, is plausible, but other weaknesses must be considered. The obvious is that boats (or motors) may be used in areas other than their places of registrations. Also, state numbering regulations vary to an extent, and many registrations are valid for lengths of time other than one calendar year. All of these factors make it difficult for a user to acquire the number of boats registered in an AQCR, especially if it is an interstate region. The user is encouraged to use common sense when confronted with these obstacles. Even under these conditions, when used properly, the program will give reasonable estimates of emissions.

To summarize, the input data and indicator parameter which must be supplied by the user of the computer program are:

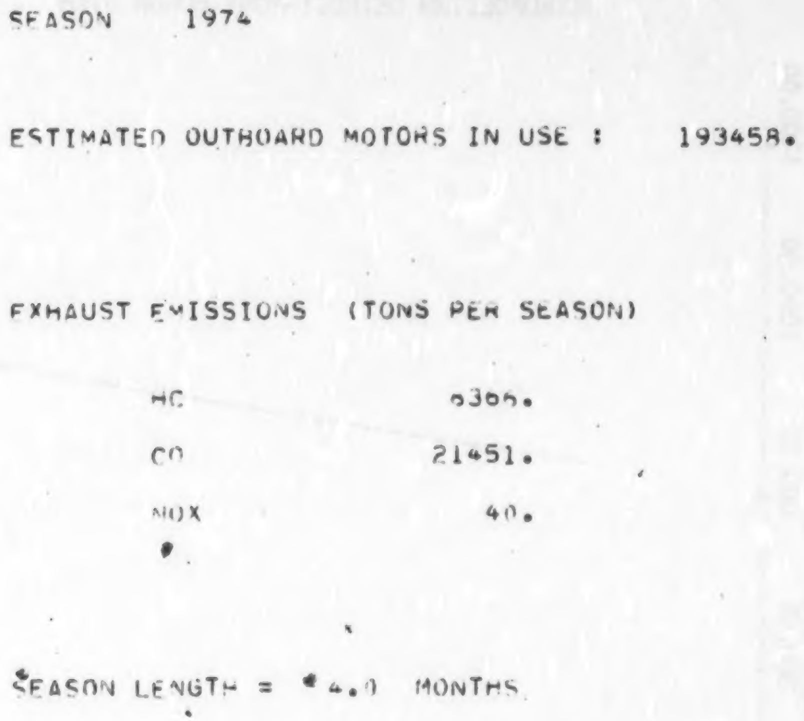
1. Number of boats registered in AQCR (this information, by county, is normally available from a State's Department of Natural Resources, Department of Motor Vehicles, etc.)
2. Length of boating season, in months
3. Projected growth rate of outboard motor population in the AQCR, in percent increase per year.

A complete description of the required format for the input data is included in Appendix 6.

Figure 19 is a sample of the printed computer output. Estimated outboard motor population is listed for the AQCR, as well as the corresponding seasonal exhaust emissions. Figures 20 and 21 are the plotted outputs showing, in this case, HC and CO emissions from outboards in the Detroit-Port Huron AQCR from 1974 to 1990, reflecting a projected growth rate of 0.9% per year.

Comparison with Other Air Pollution Sources

Table 35 lists the emissions inventory of the Metropolitan Detroit-Port Huron Air Quality Control Region for a four month season in 1975. Emissions from outboard motors are as predicted by the computer program, and other source emissions are from the National Emissions Data System as of June, 1975 [13]. Since the use of out-



```
SEASON     1974


ESTIMATED OUTBOARD MOTORS IN USE :     193458.



EXHAUST EMISSIONS  (TONS PER SEASON)

            HC                      6366.

            CO                     21451.

            NOX                       40.



SEASON LENGTH =  4.0  MONTHS
```

Fig. 19. Sample output of outboard motor computer program

FIGURE 20

PROJECTED OUTBOARD MOTOR EMISSIONS : HC

METROPOLITAN DETROIT-PORT HURON AQCR

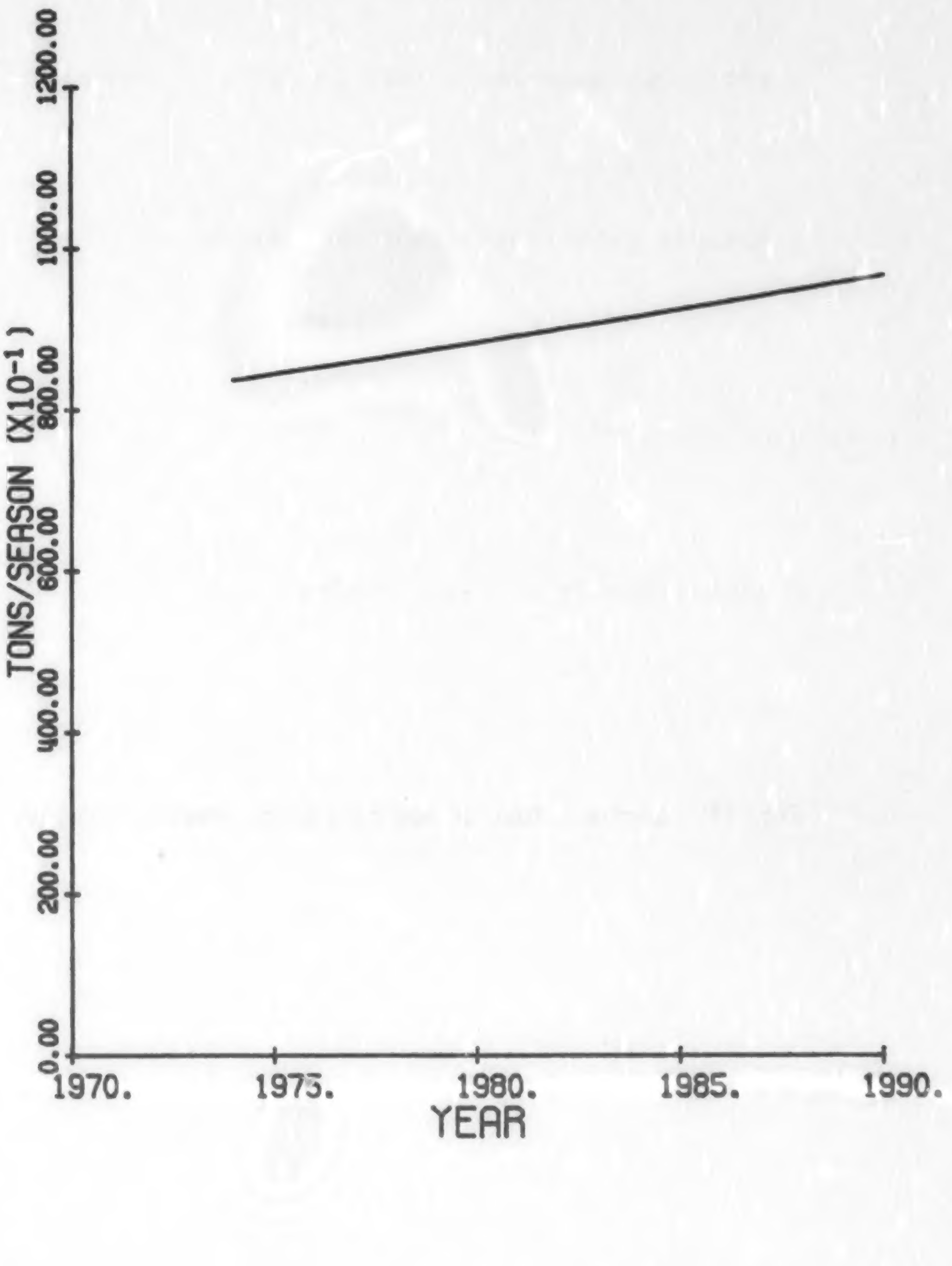


FIGURE 21

PROJECTED OUTBOARD MOTOR EMISSIONS : CO

METROPOLITAN DETROIT-PORT HURON AQCR

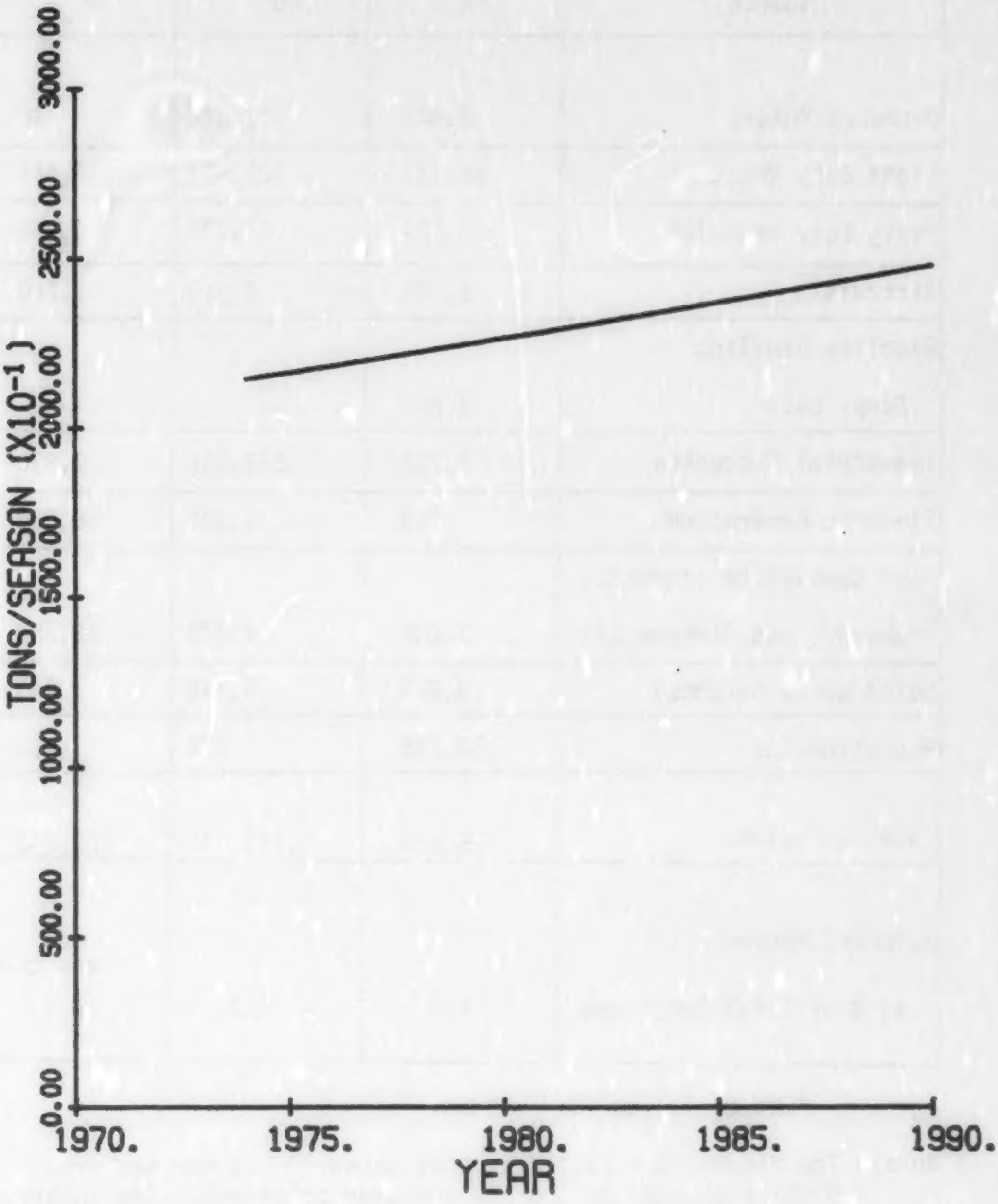


TABLE 35

EMISSIONS INVENTORY FOR THE METROPOLITAN DETROIT-PORT HURON AQCR, 1975 SEASON

Source	Tons per Season*		
	HC	CO	NO_x
Outboard Motors	8,441	21,644	40
Light Duty Vehicles	66,133	427,471	37,464
Heavy Duty Vehicles	13,824	82,925	3,969
Aircraft	2,325	5,360	1,289
Gasoline Handling Evap. Loss	7,097	--	--
Industrial Processes	9,732	655,886	3,810
Electric Generation	753	2,355	56,663
Fuel Combustion (Indust., Resid., and Commercial)	1,882	5,072	25,288
Solid Waste Disposal	4,257	9,748	693
Miscellaneous	10,786	676	26
Total Emissions	125,230	1,211,137	129,242
Outboard Motors as % of Total Emissions	6.7	1.8	less than 0.1

*Season length is 4 months.

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

board motors in this region is seasonal, the NEDS data, which are annual rates, must be adjusted. By assuming emissions are released at equal rates over the twelve month period, the data in Table 35 reflect the pollutants estimated to be emitted during the four month boating season (one-third of yearly emission rates).

Hyrdrocarbon emissions from outboard motors have the greatest relative significance in the Detroit AQCR, accounting for over six percent of the total HC emitted during the summer months. This is due to the incomplete combustion characteristics of the 2-stroke engine. And since the two major sources of HC emissions in this region are light and heavy duty vehicles, the impact of outboard motor emissions will increase as federal regulations reduce automobile and truck exhaust emissions.

PART 7

TRANSPORT REFRIGERATION UNITS

Over sixty percent of the food consumed in this country requires refrigeration at some point in its transportation from farm to consumer [1]. Other products, such as pharmaceuticals and chemicals, also may require controlled temperature transportation.

The types of refrigeration systems used in transportation are:

1. Mechanical units
   a. powered by an independent internal combustion engine
   b. powered by electricity from dockside or an on-board generator
   c. powered by the truck engine
2. Compressed gas systems
   a. liquid nitrogen
   b. carbon dioxide
3. Eutectic or cold plate systems

This Part is concerned with exhaust emissions from independent internal combustion engines that power mechanical refrigeration units (also called reefers). They are by far the most common system used in refrigerated transport, and hereafter will be referred to as transport refrigeration units.

The majority of transport refrigeration units are installed on trucks and truck-trailers. Some refrigerated rail cars also use them, but most employ a cryogenic system. The rapidly expanding refrigerated container fleet may use mechanical backup units for over-the-road operation, but utilize electric power when transported by rail or sea.

The recent growth of refrigerated carriers has led to a sizeable population of transport refrigeration units. Annual unit production has doubled over the past decade [2]. And the fact that these units often operate continously for days at a time is ample reason for analyzing their contribution to air pollution.

A transport refrigeration unit generally consists of a gasoline or diesel engine, compressor, and condenser in a single unit, with the evaporator in the same or a separate unit. Desired temperature is automatically controlled by a cycle of cooling and heating sequences. The temperature range of the unit can be from -20°F to 80°F. A properly maintained unit can have a long service life; the refrigeration unit commonly outlives the trailer on which it is installed. Units are generally mounted on the front of the truck or trailer body (called nosemounts) or, less frequently, on the underside (undermounts). Larger units used on trailers are normally diesel powered but some are gasoline. Units used on straight trucks are nearly all gasoline powered. Some gasoline units are designed for adaption of propane fuel, but these are not considered here.

The following sections estimate exhaust emissions for the three types of transport refrigeration units.

1. Gasoline powered units in straight trucks
2. Gasoline powered units in trailers
3. Diesel powered units in trailers

A note on terminology is needed. A straight truck, or simply, truck, consists of a cab and non-detachable body. It is called a single unit truck. A trailer is the detachable body unit of a truck-trailer (or tractor-trailer) combination. As used in this report they do not refer to recreational or travel trailers.

Estimation of Emissions in a Selected AQCR

As with many of the categories covered in this research, transport refrigeration units have become a necessary part of urbanized society. Since large population centers are great distances from food sources, refrigerated transportation is essential for perishable and frozen foods. And, for a host of complex reasons, transportation in this country has focused on an elaborate network of roads. Even though many people think expressways and superhighways carry the majority of vehicle traffic, in reality it is the smaller streets and roads of urban areas which are the major transportation links. It follows that use of transport refrigeration units is most heavy in large cities. As will be shown the majority of units are not used on truck-trailer combinations, but rather on small intra-city delivery trucks.

For these reasons the area for which emissions from refrigeration units will be studied is the Metropolitan Los Angeles Air Quality Control Region. This region is well known for its labyrinth network of roads serving the nation's second largest population center. Over ten percent of the nation's trucks are registered in California, with about forty percent of these registered in the LA AQCR [3,4,5].

The Metropolitan Los Angeles AQCR consists of the following counties and portions of counties:

Orange County
Ventura County
Los Angeles County, portion
Riverside County, portion
San Bernadino County, portion
Santa Barbara County, portion

The region has an area of 9,108 square miles, and a 1970 population of 9.8 million.

At the time of this study the most recent information regarding truck registrations is for 1974, so this is taken as the base year.

The parameters needed to estimate emissions from transport refrigeration units in the LA AQCR are:

1. Unit population in AQCR
2. Average usage (hours per year)
3. Average engine size (horsepower)
4. Average engine load factor
5. Emission factors (grams of pollutant per horsepower-hour)

These parameters are developed for each of the unit types in the following sections.

Unit Population in AQCR

The first step toward determining the regional population of transport refrigeration units is to determine the national population.

Two sources provide data which can be used for a starting point. The 1972 Census of Transportation states that approximately one percent of the total trucks in the U.S. have insulated refrigerated vans [3]. This is about 178,000 trucks and covers all types of refrigeration systems. The Census is based on a sample of questionnaires mailed to owners of registered trucks. If the truck is a truck-tractor which pulls a trailer, the respondent is instructed to indicate the type of trailer normally hauled. This introduces an unknown amount of error into the survey, since truck-tractors can pull all types of trailers. In other words, the Census data actually are a count of the trucks which "normally" pull refrigerated trailers, and not an accurate count of the national population of refrigerated trucks and trailers. There are more trailers in use than the truck-tractors that pull them.

The second data source, and the one which is considered more appropriate to this study, is Facts and Figures on the Refrigerated Truck Market, published by Tunnell Publications, Inc. [6]. The data show the 1969 refrigerated vehicle count by type of vehicle (small and large straight trucks and trailers) to be 260,600 vehicles. The 1974 refrigerated vehicle population is projected from the 1969 figures by the following equation:

$$\frac{\text{Refrigerated vehicles, 1974}}{\text{Refrigerated vehicles, 1969}} = \frac{\text{Total truck registrations, 1974}}{\text{Total truck registrations, 1969}}$$

This assumes the growth of refrigerated vehicles from 1969 to 1974 is proportional to the growth of the total truck fleet over the same period. According to one source this may be conservative [7]. The trucking industry as a whole felt the economic slowdown of the early 1970's, whereas the refrigerated trucking business has continued to show a steady increase.

The total number of trucks registered in the U.S. for the two years in question are:

	Total trucks registered in the U.S. [4].
1969	17,882,000
1974	24,544,000

Using the above ratio the 1974 U.S. refrigerated vehicle population is calculated as shown in Table 36 .

The next step is to estimate the percentage of refrigerated vehicles that utilize transport refrigeration units as opposed to other refrigeration systems. A major manufacturer of refrigeration units estimates that 97% of refrigerated vehicles use mechanical units [8]. In the case of straight trucks some are refrigerated by a compressor driven off the truck engine, which do not qualify as transport refrigeration units. This power take-off system can only be used in small trucks (panel trucks or compact vans). Considering that for most owners of small trucks investment in a transport refrigeration unit would be unreasonable, it is estimated that only 20% of small refrigerated trucks use an independently powered unit. A large straight truck cannot be refrigerated by a power take-off system, so 97% are assumed to use transport refrigeration units. The remaining 3% use non-mechanical systems. Essentially all units used by straight trucks are gasoline powered [9,10].

It is also estimated that 97% of refrigerated trailers use transport refrigeration units [8]. Trailer units may be electric, but in over-the-road operation electricity is supplied by a diesel generator, so pollutants are still being emitted. As stated, most trailer units are diesel powered; a few gasoline models are available for small trailers. An estimate of 95% diesel-5% gasoline is made for trailer units.

Table 37 lists the 1974 U.S. population of transport refrigeration units resulting from the above estimates and assumptions.

Extrapolation of national population to regional population is based on the assumption that the percentage of total U.S. refrigeration units operating in a region is equal to the percentage of total U.S. trucks registered in that region. Obviously not all trucks registered in a region operate exclusively in that area, particularly truck-trailer combinations. But as shown, over half the transport refrigeration units are used on straight trucks which operate mostly within a limited area. A further argument can be made that truck and trailer activity in a region is directly proportional to the number of registered trucks. A resident truck may leave the region, but non-resident trucks will enter in direct relation to the amount of transportation activity occuring in the region.

For most AQCR's obtaining the number of registered trucks is simply a matter of checking county motor vehicle registration statistics. Since Los Angeles AQCR contains portions of counties, the process is a bit more tedious. First, the number of trucks regis-

TABLE 36

ESTIMATED REFRIGERATED VEHICLE POPULATION IN THE UNITED STATES, 1974

Small Straight Trucks	18,700
Large Straight Trucks	232,000
Total Straight Trucks	250,700
Trailers	107,000
Containers	12,900
Total Refrigerated Vehicles	370,600

TABLE 37

ESTIMATED TRANSPORT REFRIGERATION UNIT POPULATION IN THE UNITED STATES, 1974

Units in Straight Trucks	228,700
Units in Trailers	103,900
Diesel Powered	98,700
Gasoline Powered	5,190

tered in the State of California is found to be 2,379,700 [4]. (This is 10.1% of the total 1974 U.S. truck fleet, corresponding exactly with Census of Transportation data which show that 10.1% of the nation's insulated refrigerated vans are in California). The California Air Resources Board estimates that 38.6% of the State's heavy duty vehicle registrations are in the LA AQCR [5]. Therefore, it is estimated that 918,600 trucks are registered in the LA Region. From this figure the 1974 population of transport refrigeration units in the LA AQCR are calculated.

Average Usage

The annual operating time of a transport refrigeration unit is highly variable, particularly for straight trucks. Representatives of two major manufacturers estimate an average usage of between 2000 and 4000 hours per year for trailer units [8,11]. A number of large trucking firms were contacted, but said records were not kept on unit operating times. A few responded that 3000 hours per year was reasonable.

The 1972 Census of Transportation shows the average annual mileage of an insulated refrigerated truck-trailer combination to be 72,000 miles. If an average speed of 40 mph is used this means on-the-road time of 1800 hours. But a major portion of unit usage occurs when the trailer is stopped either at driver rest stops, warehouses, or loading/unloading points. It does not seem unreasonable that 1200 hours per year (or about 24 hours per week) would be accumulated while the vehicle is not moving. Also, there is a trend toward multi-compartment trailers with two or even three compartments separated by bulkheads. In the past truckers would wait until they had a full load of refrigerated goods to haul. Now they can travel with multi-temperature loads. This trend will increase the operating hours of the refrigeration units. In conclusion, the average annual usage of a transport refrigeration unit used in a trailer (both diesel and gasoline) is estimated to be 3000 hours per year.

Units in straight trucks are used under much more variable conditions. Most are used for intra-city deliveries and do not operate 24 hours a day. One estimate of their use is 50 hours a week [8]. If this is extended to a year the annual usage becomes about 2500 hours per year, and this is considered typical.

Table 38 lists the annual hours transport refrigeration units can be expected to operate in the Los Angeles AQCR. (Annual operating hours equal unit population times annual usage).

TABLE 38

ESTIMATED OPERATING HOURS OF TRANSPORT REFRIGERATION UNITS IN THE LOS ANGELES AQCR, 1974

	Hours (x 10^{-6})
Units in Straight Trucks	22.4
Units in Trailers, Total	12.2
Diesel Powered	11.6
Gasoline Powered	0.6

Average Engine Size

This parameter is easily acquired. Sales brochures of the two major transport refrigeration unit manufacturers list rated engine horsepower for each model they produce [9,10]. In the case of gasoline powered units four different engines are used with an average horsepower of 11.75 hp. Four engines are also used on the diesel powered units with an average of 26.0 hp.

Average Engine Load Factor

The following description of the operation of a typical diesel refrigeration unit is taken from a manufacturer's sales brochure.

> Engine operates continously after initial start. Desired temperature maintained automatically through four-stage operational sequence: HIGH SPEED COOL until temperature nears thermostat setting, then at LOW SPEED COOL until setting is reached or more refrigeration is called for. If outside temperature drops below thermostat setting, unit operates at LOW SPEED HEAT or HIGH SPEED HEAT as required [9].

It is evident that these diesel engines operate under much more constant conditions than engines used for other purposes. A typical cycle of time spent at high and low engine speeds for a trailer unit refrigerating a pre-cooled load of meat to 35°F with an outside ambient temperature of 70°F would be 3 minutes at high speed cool, then 20 minutes at low speed cool, then repeating the cycle of 3 minutes at high speed, etc.. A diesel engine rated at 24 hp at 1900 rpm is developing about 30% of rated hp at low speed operation, about 60% at high speed, and about 75% at maximum load conditions (initial temperature pulldown or very high ambient temperature operation)[11].

An average duty cycle for a trailer unit is difficult to estimate. The cycle described above is for optimum conditions: pre-cooled load, no door openings, well insulated body, 35°F box temperature. Factors which must be considered--all of which will increase load on the engine are:

1. Box and cargo temperature often are not pre-cooled to carrying temperature
2. Cargo temperature often must be less than 35°F, such as frozen foods
3. Efficiency of trailer insulation often deteriorates with age, particularly polyurethane
4. If the unit is not maintained properly (cleaned, oil changed, defrosted, etc.) it will not operate as efficiently
5. Service load (door openings) may add significantly to total heat gain
6. Other factors influencing heat gain are ambient transmission, solar and ground radiation, product respiration, trailer breathing, and evaporator fan heat

Taking these factors into account a typical duty cycle for diesel refrigeration units is estimated, and the corresponding load factors discussed above are used to derive a typical load factor in Table 39. The average load factor of a diesel powered unit is thus estimated to be 0.40.

Truck body insulation techniques are not as well developed as trailer bodies. More door openings occur in delivery trucks than in long haul trailers. Smaller operators often cannot afford regular maintenance on their refrigeration equipment. All these factors make loads highly variable on truck (gasoline) refrigeration units.

Most gasoline powered units operate at a governed engine speed until desired temperature is attained, the speed is then reduced to fast idle disengaging a centrifugal clutch and stopping the compressor. In some gasoline units the engine stops and starts in response to thermostat demand.

Because of variations in operating conditions no typical duty cycle can adequately be estimated for gasoline powered transport refrigeration units, but a manufacturer agreed that 0.50 is a reasonable estimate for an average load factor [11]. This is used for all gasoline units.

TABLE 39

CALCULATION OF A TYPICAL LOAD FACTOR FOR A TRAILER REFRIGERATION UNIT

Operating Mode	Engine Load Fraction of Rated hp	Estimated Time Spent in Mode	Time Wghtd Load Factor
Low Speed, Normal	0.30	0.69	0.20
High Speed, Normal	0.60	0.19	0.11
Maximum Condition	0.75	0.12	0.09
			0.40

Emission Factors

Emission factors for diesel engines are derived from tests performed at Southwest Research Institute for the U. S. Environmental Protection Agency [12]. One of the engines tested, a Mercedes Benz OM 636, is used on a number of diesel powered refrigeration units. It is also the power source of the generator which runs the electric units. Thus, it can be considered very representative of diesel engines used in transport refrigeration units, and the following diesel emission factors are based on tests of this engine.

Applying the individual mode emission data from the SWRI report to the previously estimated duty cycle results in the following conditions.

1. "Low speed" operation will be represented by 25% load at 1400 rpm
2. "High speed" operation will be represented by 50% load at 2100 rpm
3. "Maximum" conditions will be represented by 75% load at 2100 rpm

The emission factors derived from these conditions for the aforementioned duty cycle are calculated in Table 40.

In related tests SWRI measured emissions from small horsepower gasoline engines [13]. Unfortunately, none of the engines tested are currently used in transport refrigeration units. Two of the engines tested, however, are of the same manufacturer and similar horsepower as engines used in refrigeration units. They are considered most representative, and are 1) Kohler K482, 2 cylinder, 18 hp engine, and 2) Wisconsin S-12D, 1 cylinder, 12.5 hp engine.

Another problem is that the SWRI mode emission tests do not conform exactly to the expected operation of a refrigeration unit engine. The engines operate at governed speed (2600-2700 rpm) and at fast idle. Since emissions from gasoline engines generally vary more than emissions from diesels, it is decided to base emission factors on a large number of data points even if an engine never really operates in that exact mode. Therefore, emission factors are calculated by equally weighing the individual mode emission data for each engine as shown in Table 41. The composite emission factors correspond to an average load factor of somewhat less than 0.50, but are considered to be the best estimate to be obtained from the available data.

Base Year Emissions

Using the parameters identified in the preceding sections it is possible to estimate annual mass emissions of HC, CO and NO_x caused by transport refrigeration units in the Metropolitan Los Angeles Air Quality Control Region. The general equation is:

(Unit population in AQCR)x(Avg hours of use/year)
x (Avg engine hp)x(Avg load factor)x(Grams of pollutant/hp-hr)
x(Unit conversion factor) = Tons of pollutant/year

TABLE 40

CALCULATED EMISSION FACTORS FOR DIESEL POWERED TRANSPORT REFRIGERATION UNITS

Operating Mode & Time Factor	Grams per Horsepower-hour					
	HC		CO		NO_x	
	(Mode E.F.)	x (T.F.)	(Mode E.F.)	x (T.F.)	(Mode E.F.)	x (T.F.)
Low Speed (0.69)	1.59	1.09	4.56	3.13	6.50	4.47
High Speed (0.19)	0.79	0.15	2.87	0.54	3.34	0.63
Maximum (0.12)	0.38	0.05	1.68	0.21	3.00	0.37
Composite Emission Factors		1.29		3.88		5.47

Notation: E.F. = Emission Factor

T.F. = Time Factor

TABLE 41

CALCULATED EMISSION FACTORS FOR GASOLINE POWERED TRANSPORT REFRIGERATION UNITS

		Mode Emissions at Percent Load (g/hp-hr)								
		HC			CO			NO_x		
Engine	RPM	25%	50%	75%	25%	50%	75%	25%	50%	75%
Kohler	1800	41.3	--	--	576.	--	--	0.91	--	--
	2300	35.0	19.6	21.5	508.	311.	307.	1.40	1.89	5.60
	3000	26.1	11.6	9.8	608.	250.	198.	1.44	2.86	4.87
Wisconsin	1800	18.9	--	--	308.	--	--	2.49	--	--
	2300	20.1	5.9	3.7	327.	22.	13.	2.60	10.6	13.8
	3000	16.1	9.6	8.9	350.	269.	246.	3.42	4.06	5.15
Composite Emission Factors			17.7			306.			4.36	

Table 42 lists the estimated exhaust emissions from each type of transport refrigeration unit for the base year of 1974.

TABLE 42

EMISSIONS FROM TRANSPORT REFRIGERATION UNITS IN THE LOS ANGELES AQCR, 1974

	Tons per Year		
Gasoline Powered:	HC	CO	NO_x
Units in Straight Trucks	2,570	44,300	632
Units in Trailers	70	1,210	17
Total, Gasoline Powered Units	2,640	45,500	649
Diesel Powered:			
Units in Trailers	171	515	726
Total Emissions	2,810	46,000	1,370

Projected Growth Analysis

All indications are that the use of transport refrigeration units in the trucking industry will continue to grow. Annual unit production has increased 100% in the past decade [2]. There also is a definite trend toward greater use of refrigerated trailers and less use of refrigerated straight trucks [7].

The only data related to recent growth rates of transport refrigeration units are the 1967 and 1972 Census of Transportation [3].

Although data regarding vehicles designated as "insulated refrigerated vans" (IRV's) do not apply directly to populations of refrigeration units, it can be used to indicate common trends. The following census data are useful:

1. The number of IRV's that are single units increased 13.0% from 1967 to 1972
2. The number of IRV's that are combinations increased 56.1% from 1967 to 1972
3. The number of all types of trucks in the U.S. increased by 28.5% from 1967 to 1972

If the years 1967 through 1972 can be considered representative of growth in the transportation industry, then it is apparent that the growth rate of refrigerated straight trucks is approximately half the growth rate of total trucks. Likewise the growth rate of refrigerated trailers is about twice that of total trucks.

Continuing along this line, the increase in annual U.S. truck registrations over the years 1965 to 1974 has been calculated to be an average of 5.9% per year [4]. Accounting for the fact that the trucking industry can be expected to expand at a slightly less rapid pace than it experienced in the past ten years, it can be projected that a growth rate of 5.0% per year is reasonable over the next 15 years.

Summarizing, it appears that refrigerated transportation will continue to be a vital part of this country's food distribution network. The amount and variety of perishable and frozen foods in all markets shows no evidence of decline. Thus, considering the above data it is estimated that the annual population growth rate of transport refrigeration units used in straight trucks will be half the growth of the total truck population, or 2.5% per year. Similarily, the growth rate of units used in trailers will be twice the rate of total trucks, or 10.0% per year.

These growth rates are projected to hold constant through 1990. It is further assumed that all units used in straight trucks will be gasoline powered, and trailer units will continue to be 95% diesel, and 5% gasoline. The projections apply to the U.S. as a whole and to individual Air Quality Control Regions as well.

Predictive Computer Program

The computer program which can be used to estimate mass emissions of transport refrigeration units in any Air Quality Control Region in the country for any year from 1974 to 1990 is listed in Appendix 7. The program estimates emissions for the following types of transport refrigeration units:

1. Gasoline powered units in straight trucks
2. Gasoline powered units in trailers
3. Diesel powered units in trailers

Parameters considered independent of individual AQCR characteristics and assigned constant values are emission factors, usages, engine horsepowers and load factors. Input parameters for the category are 1) projected growth rate of the transport refrigeration unit population used in straight trucks, and 2) projected growth rate of the unit population used in trailers. The growth rates are constant annual increases, compounded yearly.

As is the case with most of the other categories in this report, there is no direct information available on the category population in a given AQCR. Therefore, an indicator parameter must be developed which will relate some obtainable AQCR (or more specifically, county) data to the 1974 population of transport refrigeration units. As discussed in a previous section, the number of refrigeration units in an AQCR can be considered proportional to the number of trucks registered there. The factor which actually determines the amount of air pollution is the total hours of operation of all transport refrigeration units in that region. The assumption being made here is that this activity is proportional to the amount of regional truck traffic which in turn is related to the number of trucks registered in the area. The registration of a truck does not limit its activity to that county or even that state, and a sizeable portion of activity is caused by "non-resident" trucks. But, lacking more explicit information, truck traffic in an area and hence refrigeration unit activity, can be related to the number of trucks "residing" (registered) in the area.

The indicator parameter for transport refrigeration units is total truck registrations in the AQCR. Registration data by county are available from State Motor Vehicle Departments, or their equivalent. At the time of this research the most recent data were for 1974, thus the computer program user is encouraged to enter input data pertaining to 1974 even though more current data may be available.

The ratio used in the program to estimate the transport refrigeration unit AQCR population is:

$$\frac{\text{TRU population in AQCR}}{\text{TRU population in U.S.}} = \frac{\text{Trucks registered in AQCR}}{\text{Trucks registered in U.S.}}$$

A similar ratio is used to estimate units used in straight trucks and units used in trailers. As discussed 100% of straight truck units are assumed to be gasoline powered, and 95% of trailer units are diesel powered. Average horsepower, load factor, emission factors and hours of usage are values described in previous sections.

To summarize, the input data which must be supplied by the user of the computer program are:

1. Total number of trucks (all types) registered in the AQCR in 1974
2. Projected growth rate of the transport refrigeration unit population used in straight trucks
3. Projected growth rate of the transport refrigeration unit population used in trailers

A complete description of the required format for the input data is included in Appendix 7.

Figure 22 is a sample of the program printed output the user may request for any year from 1974 through 1990. Listed are the estimated hours of yearly operation for each type of refrigeration unit, and the corresponding mass emissions.

Figures 23, 24, and 25 are the plotted yearly emissions of HC, CO, and NO_x from transport refrigeration units in the Los Angeles AQCR over the time span 1974 to 1990. They are based on projected growth rates of 2.5% per year for units in straight trucks and 10.0% per year for units in trailers.

Comparison with Other Air Pollution Sources

The 1976 emissions inventory for the Metropolitan Los Angeles Air Quality Control Region is listed in Table 43 . Emissions from transport refrigeration units are those predicted by the computer program. Other source emissions are from the National Emissions Data System as of May 1, 1976 [14].

At the present time transport refrigeration units are not a significant source of air pollution in this region. Even though there are probably more refrigerated vehicles operating in this area then in any other part of the country, light duty vehicles are by far the primary sources of emissions in Los Angeles. It is interesting to note, however, that carbon monoxide emissions from refrigeration units (mainly from gasoline powered units) are greater than CO

```
YEAR    1974

ESTIMATED HOURS OF TRANSPORT REFRIGERATION UNIT OPERATION :

  UNITS IN STRAIGHT TRUCKS, GASOLINE POWERED      22369376.
  UNITS IN TRAILERS, TOTAL                        12187614.
    DIESEL POWERED                                11578233.
    GASOLINE POWERED                                609382.


                                         EXHAUST EMISSIONS  (TONS PER YEAR)
                                           HC          CO          NOX
GASOLINE POWERED UNITS
  IN STRAIGHT TRUCKS                     2567.       44328.        632.
  IN TRAILERS                              70.        1208.         17.
  TOTAL                                  2637.       45536.        649.

DIESEL POWERED UNITS IN TRAILERS, TOTAL   171.         515.        726.

TOTAL EMISSIONS                          2808.       46051.       1375.
```

Fig. 22. Sample output of transport refrigeration unit computer program

FIGURE 23

PROJECTED TRANSPORT REFRIGERATION UNIT EMISSIONS: HC

METROPOLITAN LOS ANGELES AQCR

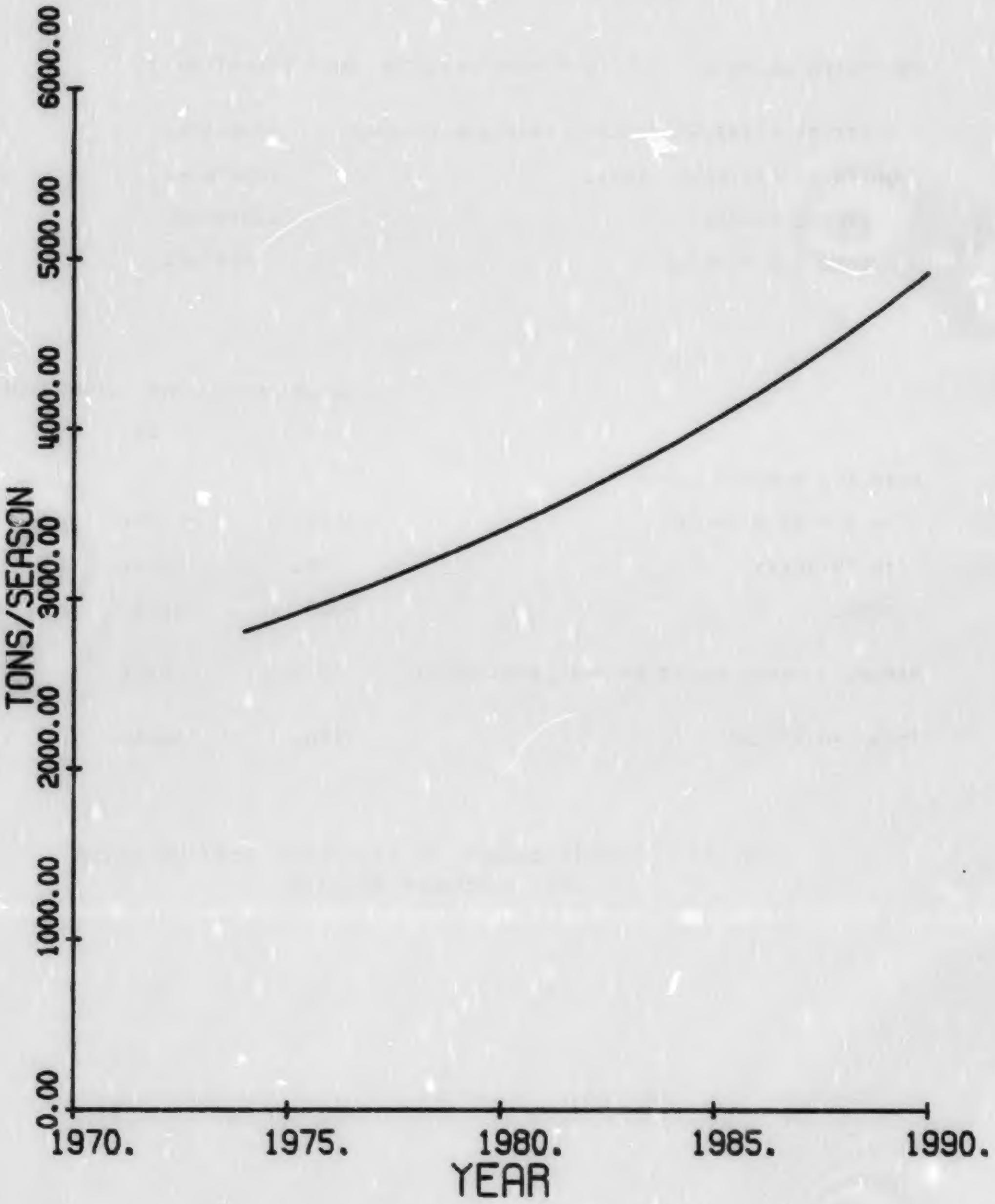


FIGURE 24

PROJECTED TRANSPORT REFRIGERATION UNIT EMISSIONS: CO

METROPOLITAN LOS ANGELES AQCR

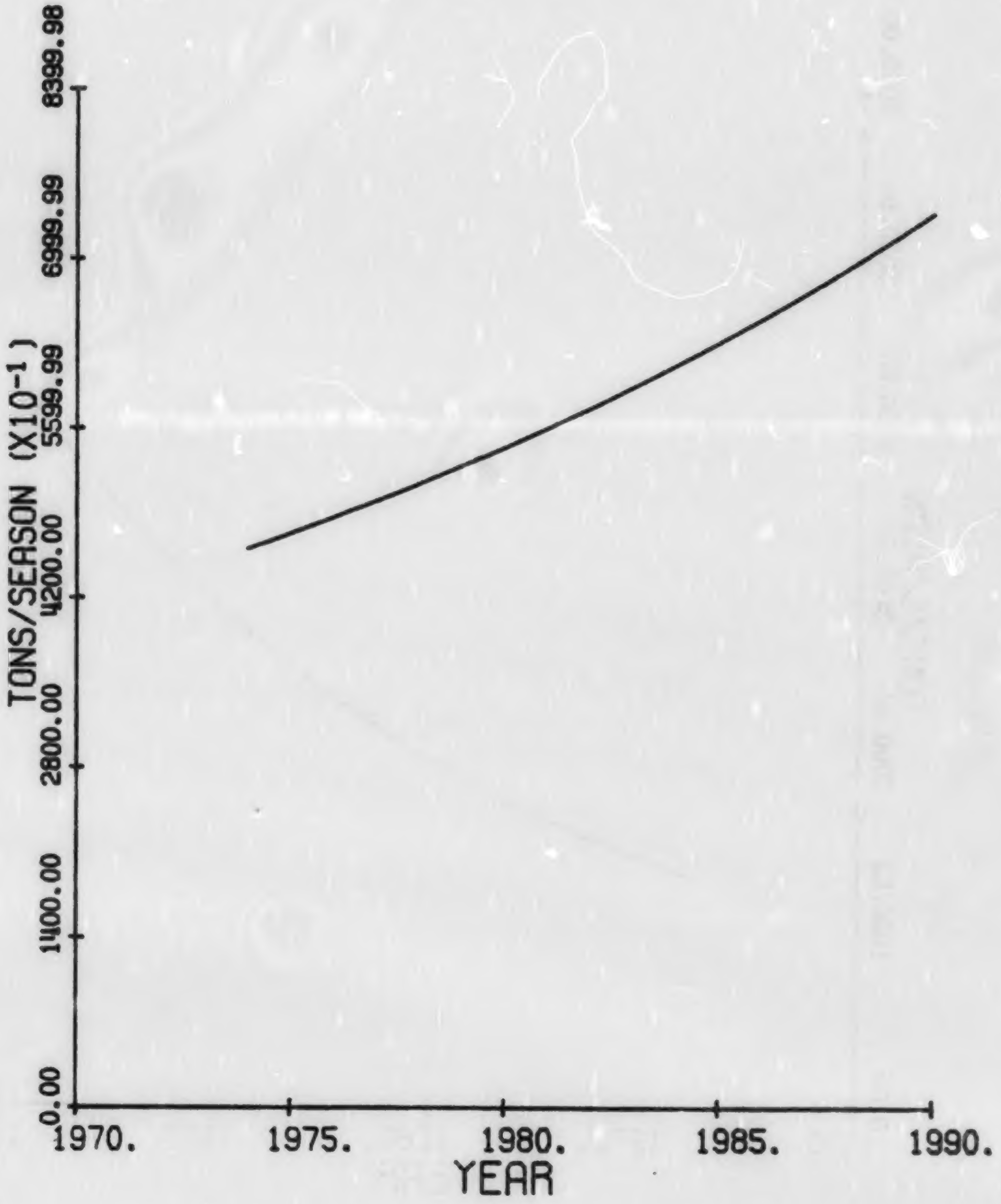


FIGURE 25

PROJECTED TRANSPORT REFRIGERATION UNIT EMISSIONS: NOX

METROPOLITAN LOS ANGELES AQCR

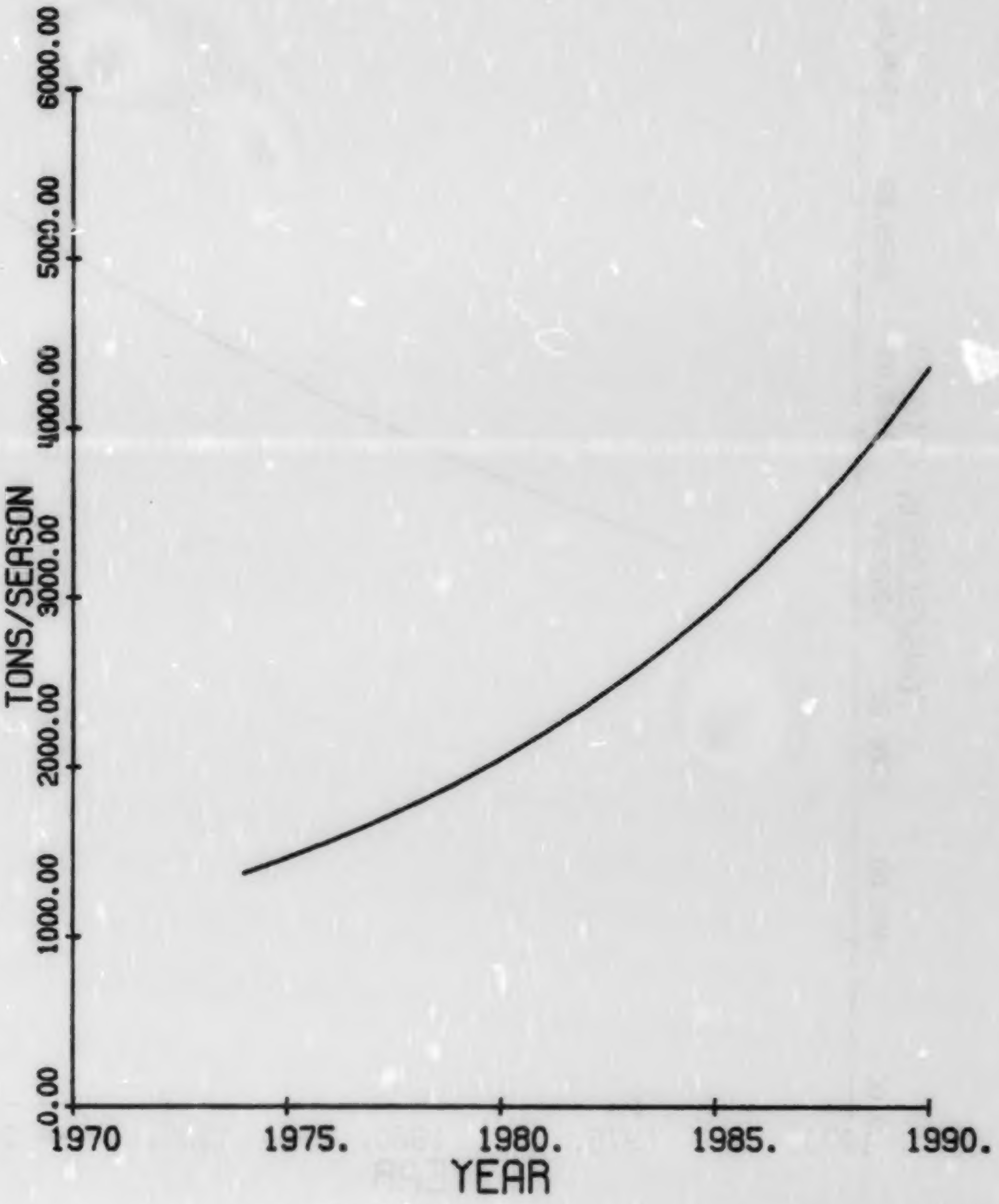


TABLE 43

EMISSIONS INVENTORY FOR THE METROPOLITAN LOS ANGELES AQCR, 1976

Source	Tons per Year		
	HC	CO	NO_x
Transport Refrig. Units	2,989	48,657	1,563
Light Duty Vehicles	487,430	3,145,300	277,048
Heavy Duty Vehicles	70,503	409,406	50,109
Aircraft	13,780	28,973	5,262
Gasoline Handling Evap. Loss	58,624	--	--
Industrial Processes	194,585	5,847	38,036
Electric Generation	4,587	3,299	156,152
Fuel Combustion (Indust., Resid., and Commercial)	6,192	7,081	58,347
Solid Waste Disposal	58,775	173,171	4,144
Miscellaneous	139,428	4	82
Total Emissions	1,036,893	3,821,738	590,743
Transport Refrig. Units as % of Total Emissions	0.3	1.3	0.3

Note: The figures are listed as they appear in either the predictive program or the EPA computer print-out. The number of significant figures does not reflect the accuracy of any estimate.

emissions annually emitted by aircraft, industrial processes, generation of electricity, and fuel combustion. It is questionable whether this is truly the case or merely an indication of weakness in present methods of compiling emission inventories.

Of course, transport refrigeration units may have greater significance as emission sources in other regions, and the computer program is designed for this purpose. The future trend in refrigerated vehicles is toward a larger fleet of trailers using diesel powered refrigeration units. A major effect will be a proportionately greater increase in NO_x emissions and less dramatic rises in HC and CO emissions. This is illustrated for the Metropolitan Los Angeles AQCR in Figures 23 through 25.

PART 8

HELICOPTERS

Although the number of non-military helicopters in the U.S. is small, about 5,000, their versatility insures an expanding future. Today helicopters are being used in offshore drilling operations, logging, forest fire fighting, ranching, and power line patrol. But their greatest application is still in metropolitan areas as air taxis for corporate and government personnel, for law enforcement and banking, and by the construction industry. This Part analyzes helicopters as a source of air pollutants in an area of their extensive use.

Helicopter engines are either reciprocating or turboshaft. There are more piston engine helicopters registered, but turbine craft account for about 65% of the total hours flown by helicopters [1,2]. The average forward speed is approximately 125 miles per hour, with civilian helicopters rarely flying above 1,000 feet altitude. Thus, the engine exhaust is always emitted below the atmospheric mixing height.

Estimation of Emissions in a Selected AQCR

The Air Quality Control Region with probably the greatest amount of helicopter traffic is the New Jersey-New York-Connecticut

AQCR. This region, as described in the previous analysis on merchan vessels, includes New York City, Long Island, northeastern New Jerse and southwestern Connecticut. New York is one of three cities in the country to have a helicopter fleet in air carrier operation (the others are Chicago, and San Francisco-Oakland). The carrier, New York Airways, flies over 5,000 hours a year in scheduled service, al within the boundaries of the AQCR [3]. Another major reason for choosing this region is the accessibility of records on helicopter movements. Most helicopters are not engaged in scheduled service. They are privately owned and are not required to file flight information with any government agency. They often take-off and land at private helipads or simply an open patch of land. Even major airports do not compile movements of general aviation helicopters. New York, on the other hand, has several public access heliports with complete records of the craft they handle.

Originally, helicopter emissions were to have been estimated for 1974, but it soon became evident that helicopter use, at least in the northeastern part of the country, was severly curtailed by the fuel shortage in that year. It has since recovered, but the most recent data for a "normal" year is 1973 so this is chosen as th base year. The parameters needed to estimate annual emissions from helicopter engines are:

1. Hours of operation in the AQCR
2. Emission factors (lbs of pollutant per hour)

Hours of Operation in the AOCR

The total hours of helicopter operation in the AOCR in 1973 is listed in Table 44 by engine type and use. The relevant figure is engine hours per year which accounts for those helicopters with two engines. The first user is New York Airways, the helicopter air carrier. Their four Sikorsky twin engine turbine craft flew 5,200 hours of service in 1973 [4].

The next category, law enforcement and government, consists of police departments and The Port Authority of New York and New Jersey. The Port Authority owns two turbine engine helicopters, one is a twin engine. These craft were operated approximately 2,000 hours [5]. The following police departments were contacted about their use of helicopters: New York City, New York State, New Jersey State, Nassau County, and Suffolk County [6-10]. These police units operate a combined fleet of 20 helicopters (New York State Police craft spend less than 100 hours a year in metropolitan New York City, so they are not included). Thirteen are turbine and all are single engine craft. As the data indicate these helicopters experience substantial usage.

The third category are itinerant helicopters which can be accounted for with available helicopter movement records. Itinerant includes corporate, private, air taxi, and sightseeing helicopters. The hours of operation are estimated from the number of take-offs and landings made in 1973 at the four major Manhattan heliports: Midtown (W. 30th St.), Downtown (Wall St.), East 34th Street, and 60th Street [11-13]. For example, these heliports recorded 33,000 movements of corporate, private, and air taxi helicopters in 1973. This is equivalent to 16,500 flights and, assuming 15 minutes per flight, approximately 4,200 flight hours. Similar calculations are made with sightseeing helicopters assuming 30 minutes for an average flight. Sixty percent of these hours are assumed to have been flown in turbine powered craft.

The final category is unaccountable itinerant flights. Helicopter activity to this point has included only itinerant take-offs and landings from four Manhattan heliports. There are certainly many more from airports, private pads, etc., about which there is no information. Even the major airports (Kennedy, LaGuardia, and Newark) record movements only of scheduled flights. An estimate of these unaccountable movements is made by the following procedure. The Federal Aviation Administration estimates the average general aviation helicopter is flown 368 hours a year [1]. On December 31, 1973, there were 98 helicopters registered in the New Jersey-New York-Connecticut AQCR [14]. Using the FAA figures they would have flown about 36,000 hours in 1973. Of course, not all this flight would have taken place in the AQCR, but non-resident craft fly into the region to offset this. The three previous categories account for about 26,000 flight hours so, as a rough estimate, the unaccountable itinerant flights are assigned the difference of 10,000 hours. All is assumed to be flown by single engine craft, 60% being turbine powered.

Emission Factors

Emissions from fixed-wing aircraft are typically characterized in terms of a landing-takeoff (LTO) cycle. As defined by the U.S. Environmental Protection Agency the LTO cycle "includes all normal operation modes performed by an aircraft between the time it descends through an altitude of 3,500 feet on its approach and the time it subsequently reaches the 3,500 foot altitude after takeoff" [15]. But a helicopter never flies at an altutude greater than 3,500 feet, so its emission factors must represent the entire flight and ground operations. It does not taxi but may spend time at idle.

Knowledgeable sources were contacted regarding typical helicopter duty cycles. Table 45 lists duty cycles as estimated by Hughes Helicopters Division of Summa Corp., Sikorsky Aircraft Division of United Technologies Corp., and the American Helicopter Association [16-18]. These cycles are to be taken as rough estimates of helicopter operation near metropolitan areas. That is , they may not be applicable to helicopters used in agriculture, lumbering, etc. As can be seen, the engines are most often developing 50 to 80% of full power. Both Sikorsky and AHA consider turbine and piston engine cycles to be similar, while Hughes, estimates that a turbine spends more time at high power than does a piston engine. Table 45 lists a consensus duty cycle which is used to weight helicopter emissions in the analysis which follows. The same cycle is used for both turbine and piston engines. Also listed are the specific points which

TABLE 44

[illegible] OF HELICOPTER OPERATION IN THE
NEW JERSEY-NEW YORK-[illegible]

Use	Craft Hours			Engine Hours		
	Turbine	Piston	Total	Turbine	Piston	Total
New York Airways	5,200	--	5,200	10,400	--	10,400
Law Enforcement & Gov't	8,900	3,700	12,600	9,900	3,700	13,600
Itinerant, Accountable	5,100	3,400	8,500	7,700	3,400	11,100
Itinerant, Unaccountable	6,000	4,000	10,000	6,000	4,000	10,000
Total	25,200	11,100	36,300	34,000	11,100	45,100

TABLE 45

TYPICAL HELICOPTER DUTY CYCLES

Percent of Engine Power	Percent of Time Spent in Mode				
	Source A*	Source B	Source C	Consensus	Range Mid-point (%)
Idle	5	3	↑	5	5
10-50	15	7	24 ↓	15	30
51-80	50	88	75	75	70
81-100	30	2	1	5	90

* Gas turbine duty cycle shown. Piston engine cycle is the same, except 70% of time is spent in 51-80% power range, and 10% of time is spent in 81-100% power range.

Source: A: Hughes Helicopters Div. B: Sikorsky Aircraft Div. C: American Helicopter Association are used to represent each power range.

Emission factors of gas turbine engines are derived first. Emission data were obtained for three engines that are widely used in helicopters: 1) Allison Model 250, 315 shp; 2) General Electric Model CT-58, 1250 shp; and 3) Lycoming Model T53-13, 1400 shp [19]. Data are in terms of an emission index (lb pollutant/ 1000 lb fuel) versus percent of full engine power. Emissions, in pounds per hour, at each of the selected mode power points are calculated by multiplying the emission index times the corresponding fuel flow. Mode emissions are weighted according to the estimated duty cycle to give an emission factor for each engine. Composite emission factors which represent turbine helicopter engines are obtained by assigning arbitrary weighting fractions to indicate each engine's popularity. The Allison engine powers the Bell Jet Ranger, the most popular turbine helicopter, as well as craft by Hughes and Fairchild Hiller [14]. Its emission factors are, therefore, weighted most heavily (0.60). The General Electric engine is used on Sikorsky helicopters that comprise a majority of the air carrier fleet, such as New York Airways. Its weighting fraction is 0.30. Helicopters powered by the Lycoming turbine are less numerous and a weighting of 0.10 is assigned to its emission factors.

Table 46 lists the composite emission factors of HC, CO and NO_x, in pounds per hour, derived for gas turbine engines operating in a helicopter duty cycle.

The majority of piston engines used in helicopters are manufactured by Lycoming Division of Avco Corp. Four of the most widely used

Lycoming engines are:

1. Model TVO-435, turbocharged, 260 hp (0.35)
2. Model HIO-360, fuel injected, 180 hp (0.30)
3. Model VO-540, carbureted. 310 hp (0.20)
4. Model VO-435, carbureted, 250 hp (0.15)

The numbers in parentheses are the arbitrarily assigned population weighting fractions, based on the number of registered helicopters employing that engine [4].

Emission data are available for two of these engines, the HIO-360 and VO-540. Emissions for the other two engines can reasonably be estimated by using data from engines of similar size and design which have been emission tested. The substitute engine for the VO-435 is a Teledyne Model O-470, carbureted, 230 hp engine. Emissions for the TVO-435 can best be estimated by taking the average of two turbocharged engines which bracket it in size. These are Teledyne Models TSIO-360 (225hp), and TSIO-520 (300 hp).

The emission rates measured from these engines are in pounds of pollutant per hour at various power modes [20,21]. By applying the emission rates to the helicopter duty cycle and weighting each engine by its popularity fraction, composite piston engine emission factors are derived for HC, CO, and NO_x emissions. The results of these calculations are shown in Table 46 . It should be noted that the duty cycle emissions between engines are very similar, so using the substitute engines does not appear to have introduced any unnecessary aberration into the analysis.

TABLE 46

HELICOPTER EMISSION FACTORS

Engine Type	Pounds per Hour HC	 CO	 NO_x
Gas Turbine	1.47	5.82	1.54
Piston	1.13	66.4	0.447

Base Year Emissions

Table 47 lists the emissions estimated to have been caused by civilian helicopters in the New Jersey-New York-Connecticut Air Quality Control Region in 1973. They are calculated using the parameters derived in the preceding sections by the equation:

(Hours of helicopter operation in AQCR) x (lbs of pollutant/hr)
x (Unit conversion factor) = Tons of pollutant/year

As is apparent helicopter emissions are very low and certainly insignificant when compared to emissions from other sources in this AQCR. Neither the trend toward turbine power, nor any conceivable increase in future use, would seem to be able to raise helicopter emissions to a level of concern in the New York City area. And it is doubtful that helicopter use is much greater in any other part of the country.

For these reasons further analysis of helicopter emissions is considered unnecessary at this time.

TABLE 47

EMISSIONS FROM HELICOPTERS IN THE NEW JERSEY-NEW YORK-CONNECTICUT AQCR, 1973

Engine Type	Tons per Year HC	CO	NO_x
Gas Turbine	25	99	26
Piston	6	369	3
Total Emissions	31	468	29

DISCUSSION

The preceeding parts of this report assess the impact of gaseous emissions from eight categories of mobile sources which currently are not affected by emission regulations. The analyses are conducted at the level of Air Quality Control Regions. Table 48 is a summary of the results as compiled from the individual emission inventories. The criterion used to evaluate emissions impact is the percent of total emissions caused by the particular source. For example, it is shown that farm equipment engines are responsible for approximately one-fourth of the annual NO_x emissions in the North Central Iowa AQCR. According to the chosen criterion farm equipment NO_x emissions are significant in this region. It is important to realize, however, that there are other criteria which can also be used to assess significance or impact. The most relevant would be the effects on human health. Unfortunately, this is the most difficult assessment to make. As previously discussed, mass emission rates must be converted to ambient pollutant concentrations before their health-related effects may be analyzed. Although it is beyond the scope of this research to conduct such an analysis, the implications must be understood. Thus, even though farm equipment accounts for a major portion of the air pollution in the North Central Iowa AQCR, the total emissions from all sources in that region are very low when compared to densely populated and industrialized areas as

TABLE 48

SUMMARY OF EMISSIONS FROM UNREGULATED MOBILE SOURCES

Source	Selected AQCR	Source Emissions Tons per Year $(x10^{-3})^a$				Total Emissions from all Sources Tons per Year $(x10^{-3})^a$			
		HC	CO	NO_x	SO_x	HC	CO	NO_x	SO_x
Farm Equipment	N. Cntrl Iowa	2.6	50.3	8.8	.7	42.6	444.	33.4	20.6
Merchant Vessels	NJ-NY-Conn	20.6	21.9	39.2	9.4	1,080.	4,280.	1,030.	864.
Locomotives	Chicago	4.0	4.8	12.9	2.1	760.	2,030.	463.	529.
Lawn & Garden Impl.	Detroit	4.6^b	53.8^b	$.8^b$	*	$151.^b$	$1,540.^b$	$162.^b$	*
Snowmobiles	Central Mich.	10.9^c	16.8^c	$.2^c$	*	57.3^c	$271.^c$	55.3^c	*
Outboard Motors	Detroit	8.4^d	21.6^d	$.04^d$	*	$125.^d$	$1,211.^d$	$129.^d$	*
Trans. Refrig. Units	Los Angeles	3.0	48.7	1.6	*	1,040.	3,820.	591.	*
Helicopters	NJ-NY-Conn	.03	.5	.03	*	1,080.	4,280.	1,030.	*

Notes:
- a. Unless otherwise noted emissions are for 1976.
- b. Tons per 5 month season in 1975.
- c. Tons per 3 month season in 1974-75.
- d. Tons per 4 month season in 1975.
- * SO_x emissions not estimated for this source.

shown in Table 48. The significance of farm equipment emissions according to these standards is much less.

But, whatever means are used to determine environmental impact, priorities must be chosen in any abatement program. A reduction in air pollution levels must first be achieved in areas where it is detrimental to health. Another goal should be to prevent further deterioration of air quality in any region of the country.

A large part of a study such as this involves estimating, assuming, and averaging the various parameters which influence the mass emission rates of each source category. The underlying philosophy of this research has been to use sound judgement in establishing the best estimates of these parameters from the available data. In some instances rather than choose the worst case conditions, data which are undoubtedly conservative are used. A good example of this are the emission factors. Most of the emission tests cited were conducted on new engines supplied by the manufacturers. And even though only a small number were tested, the results almost certainly indicate lower emission factors than are actually emitted by large populations of "in service" engines.

For each category the parameters which are most influential to an emissions estimate are the source population and usage within the AQCR. The other parameters--engine size, engine load factor, and emission factors based on typical duty cycles--are either well documented or else vary within a limited range which reduce their influence.

In the case of farm equipment there are extensive data on which to estimate emissions. Equipment populations are based on direct counts from the U.S. Census of Agriculture. Sufficient credibility can also be given to the average annual usage and engine horsepower figures, particularly for tractors. And as shown in Table 5, tractors account for between 80 and 90% of the total farm equipment emissions of four pollutants in the North Central Iowa Air Quality Control Region. A high degree of confidence can, therefore, be expressed in the farm equipment emissions analysis. These emissions, at least in this particular AQCR, are a significant portion of the total annual emissions (Table 7). The oxides of nitrogen are the most significant pollutants at the present time, and they will be continually increasing in future years as more farm equipment becomes diesel powered. Carbon monoxide emissions are also significant, but because they are mainly a result of gasoline tractor operation, their trend is decreasing somewhat. Farm equipment CO emissions still deserve close attention, however,

The analysis of merchant vessels also benefited from very accurate data on annual vessel movements. The weakest parameters for this category are engine emission factors. Further testing is needed on large diesel engines used in tugboats and motorships, and on marine boilers used in steamships. Even in view of possible errors in the analysis it is reasonable to conclude that emissions from merchant vessels in a heavily industrialized urban area, such as the New Jersey-New York-Connecticut AQCR, are inconsequential (Table 14). It may be a different story, however, in a less industrialized region. An example would be New Orleans, which is the nation's second busiest port. Vessel emissions of oxides of nitrogen may be significant in this region.

The method used to estimate the hours of locomotive operation in the Metropolitan Chicago AQCR are admittedly less that accurate. But any area of heavy railroad activity is almost certainly an urban center. And as shown in the Chicago AQCR, no conceivable error in estimating locomotive emissions could elevate railroads to a significant status among all sources (Table 20).

For the category of lawn and garden implements all the estimated parameters are based on reasonably accurate information. When their total seasonal emissions are compared to other sources in the Detroit-Port Huron AQCR they are found to have a low impact (Table 25). But similar conclusions cannot be extended to other regions. It is recommended that future studies of emissions from lawn and garden implements utilize the computer program developed here to analyze areas with large human populations and relatively low industrial sources.

Emissions from snowmobiles are shown to be a potentially significant source of hydrocarbon pollution in northern climates (Table 30). The method used to estimate the hours of snowmobile operation in the Central Michigan AQCR is the best information available and can be considered fairly accurate. Even though snowmobiles contribute a relatively low amount of carbon monoxide in this particular AQCR, CO emissions could also be significant in completely rural areas.

As with snowmobiles, the 2-stroke engines used by outboard motors may emit substantial amounts of unburned hydrcarbons (Table 35). The population of boats in a given area is easily acquired information, but one factor may account for unknown error in relating the number of boats to the number of outboard motors. It is the amount of boat trailering which permits boat owners to operate their craft anywhere they choose. There is no easy way to estimate the amount of trailering into or out of a region, and this should be considered when interpreting outboard motor emissions.

The use of transport refrigeration units is growing, but as shown by the analysis of the Metropolitan Los Angeles AQCR, their emissions are insignificant (Table 43). Many of the parameters in this category are based on very general estimates. But it is doubtful that any of the estimates are in error to such an extent that refrigeration unit emissions become important in Los Angeles. Even in other regions the only possible concern may be CO emissions which are almost totally accounted for by the gasoline powered units.

It is important to note that many of the conclusions drawn above are based on the Air Quality Control Region emission inventories. For each AQCR, the most recent data were obtained from the U.S. Environmental Protection Agency's National Emission Data System. These were either 1975 or 1976 inventories. It is beyond the scope of this research to analyze the procedures used by EPA to develop this information. But, in general, emission inventories are conservative. They are continually being updated, but emission sources that have not been identified or have not provided data to EPA (in the case of point sources) are not included. Furthermore, each of the emission inventories as compiled here lists only one of the eight categories studied in this report. For example, lawn and garden implements and outboard motors are both analyzed in the Detroit-Port Huron AQCR. But the tables showing the emission inventories list only one of the categories, even though they are both used in the summer months. The overall effect is that the percentage of total emissions in the AQCR caused by the project categories may be less than that shown here. On the other hand, many of the assumptions made in the preceeding parts are conservative. The net result is that the figures are in no way absolute. But they do provide a new method for comparing relative mass emission rates of these unregulated mobile sources to other sources of emissions on a regional level.

How may the results of this research be used? The most obvious is that federal, state and local governmental agencies concerned with the protection of human health and the environment will be able to assess the need for control of the exhaust emissions from these mobile sources. The computer programs are easy to use and project the current and future emission levels. As an additional aid Table 49 lists simplified equations which can be used to quickly estimate base year emissions from each of the source categories without use of the computer programs. It is suggested that these equations be used as the initial step in an emissions analysis. If a category's total emissions as calculated by the equations deserve further study, the computer programs should then be used to provide a complete listing of emissions by sub-category and their projected growth or decline.

The mass emission rates of each category can also be included in comprehensive air pollution dispersion models. This is the end product which actually determines the quality of air in terms of pollutant concentration.

In conclusion, this research has shown that emissions from some unregulated mobile sources contribute a significant amount to the total air pollution burden in certain regions of the country. The resources needed to alleviate the problem of air pollution are great, and the computer programs provide yet another aid with which to identify some of the emission sources which are responsible for this serious situation.

TABLE 49

SIMPLIFIED EQUATIONS FOR ESTIMATING EMISSIONS

FARM EQUIPMENT (Emissions from tractors only)

Tons of Pollutant per Year (1973):

$HC = (\text{TRACTORS}) \times (0.04)$

$CO = (\text{TRACTORS}) \times (0.865)$

$NO_x = (\text{TRACTORS}) \times (0.142)$

$SO_x = (\text{TRACTORS}) \times (0.0104)$

where TRACTORS = 1969 farm tractor population in the AQCR; from the *Census of Agriculture*

MERCHANT VESSELS

Tons of Pollutant per Year:

1. Ocean Port

$HC = [(\text{TUG MILES})\times(1.91\times10^{-3})] + [(\text{SHIP MILES})\times(4.11\times10^{-3})]$

$CO = [(\text{TUG MILES})\times(1.87\times10^{-3})] + [(\text{SHIP MILES})\times(4.58\times10^{-3})]$

$NO_x = [(\text{TUG MILES})\times(3.47\times10^{-3})] + [(\text{SHIP MILES})\times(8.05\times10^{-3})]$

$SO_x = [(\text{TUG MILES})\times(7.55\times10^{-4})] + [(\text{SHIP MILES})\times(2.03\times10^{-3})]$

2. Lake Port

$HC = [(\text{TUG MILES})\times(1.52\times10^{-3})] + [(\text{SHIP MILES})\times(7.65\times10^{-4})]$

$CO = [(\text{TUG MILES})\times(1.49\times10^{-3})] + [(\text{SHIP MILES})\times(8.78\times10^{-4})]$

$NO_x = [(\text{TUG MILES})\times(2.77\times10^{-3})] + [(\text{SHIP MILES})\times(1.64\times10^{-3})]$

$SO_x = [(\text{TUG MILES})\times(6.03\times10^{-4})] + [(\text{SHIP MILES})\times(9.43\times10^{-4})]$

3. Inland Port

$HC = [(\text{TUG MILES})\times(1.91\times10^{-3})] + [(\text{SHIP MILES})\times(1.08\times10^{-3})]$

$CO = [(\text{TUG MILES})\times(1.87\times10^{-3})] + [(\text{SHIP MILES})\times(1.20\times10^{-3})]$

$NO_x = [(\text{TUG MILES})\times(3.47\times10^{-3})] + [(\text{SHIP MILES})\times(2.09\times10^{-3})]$

$SO_x = [(\text{TUG MILES})\times(7.55\times10^{-4})] + [(\text{SHIP MILES})\times(4.47\times10^{-4})]$

TABLE 49 - Continued

where TUG MILES = total miles of tug and towboat traffic in the AQCR

SHIP MILES = total miles of tanker, cargo and passenger ship traffic in the AQCR

Miles of traffic refer to vessel movements in a waterway times its length. Annual data are in Waterborne Commerce of the United States.

LOCOMOTIVES (Emissions from locomotives in a major railroad terminal center; that is, the miles of switchyard track in the AQCR are assumed to equal the miles of running track.)

Tons of Pollutant per Year (1973):

HC = (TRACK) x (0.905)

CO = (TRACK) x (1.07)

NO_x = (TRACK) x (2.89)

SO_x = (TRACK) x (0.465)

where TRACK = total miles of running track in the AQCR

LAWN AND GARDEN IMPLEMENTS

Tons of Pollutant per Season (1974):

HC = (OOHU) x (MONTHS) x (9.62×10^{-4})

CO = (OOHU) x (MONTHS) x (0.0111)

NO_x = (OOHU) x (MONTHS) x (1.58×10^{-4})

where OOHU = total owner-occupied housing units in the AQCR; from the 1970 Census of Housing

MONTHS = length of growing season, in months

TABLE 49 - Continued

SNOWMOBILES

Tons of Pollutant per Season (1973-74):

$HC = [58.5(REGIS)-7190.(DENSITY) + 4.95\times10^{6}] \times (7.08\times10^{-4})$

$CO = [58.5(REGIS)-7190.(DENSITY) + 4.95\times10^{6}] \times (1.1\times10^{-3})$

$NO_x = [58.5(REGIS)-7190.(DENSITY) + 4.95\times10^{6}] \times (1.12\times10^{-5})$

where REGIS = total snowmobile registrations in the AQCR
DENSITY = human population density in the AQCR, in persons per square mile

OUTBOARD MOTORS

Tons of Pollutant per Season(1974):

1. Short Season (6 months or less)
    $HC = (BOATS) \times (0.048)$
    $CO = (BOATS) \times (0.123)$
    $NO_x = (BOATS) \times (2.27\times10^{-4})$
2. Long Season (greater than 6 months)
    $HC = (BOATS) \times (0.072)$
    $CO = (BOATS) \times (0.185)$
    $NO_x = (BOATS) \times (3.4\times10^{-4})$

where BOATS = total boat registrations in the AQCR

TRANSPORTATION REFRIGERATION UNITS

Tons of Pollutant per Year (1974):

$HC = (TRUCKS) \times (3.06\times10^{-3})$

$CO = (TRUCKS) \times (0.0501)$

$NO_x = (TRUCKS) \times (1.5\times10^{-3})$

where TRUCKS = total truck registrations in the AQCR

IMPACT ASSESSMENT IN REGIONS PREDICTED TO EXCEED PRIMARY AMBIENT AIR QUALITY STANDARDS

The two major tenets upon which this study is based are 1) emissions from unregulated mobile sources must be analyzed on a regional rather than a national level, and 2) emissions from these sources will become increasingly significant as emissions from regulated sources are reduced. To exemplify these principles emissions in other Air Quality Control Regions are analyzed.

Table 50 lists the future levels of hydrocarbon emissions in certain AQCR's. The regions are chosen from among those that are predicted by the U.S. Environmental Protection Agency to be exceeding the primary ambient air quality standard in either 1980 or 1985. The Agency has used the Modified Rollback Model to predict if the total projected HC emissions in the region will result in ambient concentrations of oxidants greater than the air quality standard. If the region is expected to meet the standard by 1985, then only the 1980 emission levels are listed in Table 50. In each region the category of unregulated mobile sources which may be a significant factor in the region's air pollution is selected for analysis. For example, farm equipment is analyzed in the Sacramento Valley AQCR, and merchant vessels in the Puget Sound AQCR and the Southern Louisiana-Southeast Texas AQCR. The latter region includes the Port of New Orleans. The predictive computer programs developed in this report are used to predict the future HC emissions of the selected source. These emissions are then added to the Environmental Protection

Agency's projections of HC emissions from all sources in the region. The far right hand column of the table shows the percentage of total regional emissions caused by the mobile source category.

A similar analysis of carbon monoxide emissions is performed in AQCR's projected by the Environmental Protection Agency to exceed the primary ambient air quality standard of that pollutant in either 1980 or 1985. The results are shown in Table 51. Unfortunately, data are not available at this time to permit similar projections of NO_x and SO_x emissions.

These results prove that in the near future some categories of mobile sources will be contributing significant amounts of pollutants, on a mass basis, in regions with critical air pollution problems. Furthermore, these emissions must be studied on a regional basis. In a previous analysis merchant vessel emissions are shown to be of no significance in the New Jersey-New York-Connecticut AQCR at the present time, but future HC emissions from vessels are projected to be important in the Puget Sound and Southern Louisiana-Southeast Texas AQCR's. Emissions from seasonal sources--lawn and garden implements, snowmobiles, and outboard motors--can certainly be significant during the months of their use.

The final conclusion to be drawn is that broad generalizations as to the amounts of air pollution contributed by these unregulated mobile sources nationwide may be grossly misleading. The only effective way to assess their impact is on a region-by-region basis.

TABLE 50

HYDROCARBON EMISSIONS IN REGIONS PREDICTED TO EXCEED OXIDANT STANDARD

AQCR	Year	HC Emissions All Sources Tons per Year	Selected Source		
				HC Emissions Tons per Year	Percent of Total
Sacramento Valley	1980	177,000	Farm Equipment	1,200	*
	1985	168,000		1,400	*
Puget Sound	1980	126,000	Merchant Vessels	21,700	17.
S. La. - S.E. Texas	1980	372,000	Merchant Vessels	23,700	6.
	1985	297,000		30,300	10.
Dallas - Ft. Worth	1980	219,000	Locomotives	4,000	2.
	1985	215,000		4,700	2.
Houston - Galveston	1980	458,000	Locomotives	4,700	1.
	1985	410,000		5,500	1.

* Less than one percent.

TABLE 50 - Continued

AQCR	Year	HC Emissions All Sources Tons per Year	Selected Source	HC Emissions Tons per Year	Percent of Total
Metro. Baltimore	1980	155,000^a	Lawn and Garden Impl.	2,200^a	1.
	1985	154,000^a		2,300^a	1.
Minneapolis-St. Paul	1980	35,400^b	Snowmobiles	4,900^b	14.
	1985	33,800^b		6,000^b	18.
Minneapolis-St. Paul	1980	50,200^c	Outboard Motors	9,500^c	19.
	1985	46,900^c		9,900^c	21.
Phoenix-Tucson	1980	186,000	Trans. Refrig. Units	1,000	*
	1985	186,000		1,200	*

* Less than one percent

Notes: a. Tons per 6 month season.

b. Tons per 3 month season.

c. Tons per 4 month season.

TABLE 51

CARBON MONOXIDE EMISSIONS IN REGIONS PREDICTED TO EXCEED CO STANDARDS

AQCR	Year	CO Emissions All Sources Tons per Year	Selected Source	CO Emissions Tons per Year	Percent of Total
Sacramento Valley	1980	337,000	Farm Equipment	18,700	6.
Puget Sound	1980	490,000	Merchant Vessels	23,900	5.
Metro. Baltimore	1980	232,000[a]	Lawn and Garden Impl.	28,600[a]	12.
Minneapolis-St. Paul	1980	124,000[b]	Snowmobiles	7,700[b]	6.
Minneapolis-St. Paul	1980	179,000[c]	Outboard Motors	24,300[c]	14.
Phoenix-Tucson	1980	392,000	Trans. Refrig. Units	16,200	4.
	1985	238,000		18,800	8.

Notes: a. Tons per 6 month season.
b. Tons per 3 month season.
c. Tons per 4 month season.

APPENDIX 1

FARM EQUIPMENT

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

FARM EQUIPMENT

Variable Name	Description
TTR	Number of tractors in the AQCR in 1969
CR	Number of self-propelled combines in the AQCR in 1969
WR	Number of windrowers in the AQCR in 1969
FR	Number of farms in the AQCR in 1969
GRTGA	Projected growth rate of gasoline tractors in the AQCR between 1973 and 1980, in percent increase per year
GRTGB	Projected growth rate of gasoline tractors in the AQCR between 1981 and 1990, in percent increase per year
GRTDA	Projected growth rate of diesel tractors in the AQCR between 1973 and 1980, in percent increase per year
GRTDB	Projected growth rate of diesel tractors in the AQCR between 1981 and 1990, in percent increase per year
GRTGHP	Projected growth rate of the average gasoline tractor PTO horsepower, in percent increase per year

Variable Name	Description
GRTDHP	Projected growth rate of the average diesel tractor PTO horsepower, in percent increase per year
GRCG	Projected growth rate of gasoline combines in the AQCR, in percent increase per year
GRCD	Projected growth rate of diesel combines in the AQCR, in percent increase per year
GRWG	Projected growth rate of gasoline windrowers in the AQCR, in percent increase per year
GRWD	Projected growth rate of diesel windrowers in the AQCR, in percent increase per year
GRX	Projected growth rate of miscellaneous farm equipment in the AQCR, in percent increase per year
NYT	Total number of years for which printed output is desired; must be 18 or less
NY(N)	The years for which printed output is desired; must be between 1973 and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	TTR	F10.0	1
	CR	F10.0	11
	WR	F10.0	21
	FR	F10.0	31

Data Card	Variable	Format Specification	Starting in Column
2	GRTGA	F10.1	1
	GRTGB	F10.1	11
	GRTDA	F10.1	21
	GRTDB	F10.1	31
3	GRTGHP	F10.1	1
	GRTDHP	F10.1	11
4	GRCG	F10.1	1
	GRCD	F10.1	11
	GRWG	F10.1	21
	GRWD	F10.1	31
	GRX	F10.1	41
5	NYT	I6	1
	NY(N)	I6	7,13,etc.

Farm Equipment Computer Program Listing

```
C     ************  FARM EQUIPMENT PROGRAM  ************
C     'T' VARIABLES: TRACTORS
C     'C' VARIABLES: COMBINES
C     'W' VARIABLES: WINDROWERS
C     'X' VARIABLES: MISCELLANEOUS ENGINES
C     'TT' VARIABLES: TOTAL TRACTORS
C     'NT' VARIABLES: NON-TRACTOR EQUIPMENT
C     'G' INDICATES GAS POWERED
C     'D' INDICATES DSL POWERED
      DIMENSION TT(18),C(18),W(18),X(18),TG(18),TD(18),CG(18),CD(18),
     1   WG(18),WD(18),XG(18),XD(18),TGHP(18),TDHP(18),HCTG(18),
     2   COTG(18),NOTG(18),SOTG(18),HCTD(18),COTD(18),NOTD(18),
     3   SOTD(18),HCTT(18),COTT(18),NOTT(18),SOTT(18),HCCG(18),
     4   COCG(18),NOCG(18),HCCD(18),COCD(18),NOCD(18),HCWG(18),
     5   COWG(18),NOWG(18),HCWD(18),COWD(18),NOWD(18),HCXG(18),
     6   COXG(18),NOXG(18),HCXD(18),COXD(18),NOXD(18),HCNT(18),
     7   SOCG(18),SOCD(18),SOWG(18),SOWD(18),SOXG(18),SOXD(18),SONT(18),
     8   CONT(18),NONT(18),HC(18),CO(18),NO(18),NY(18),IY(18),SO(18)
      REAL LF,NOTG,NOTD,NOTT,NOCG,NOCD,NOWG,NOWD,NOXG,NOXD,NONT,NO
      READ (5,100) (TTR,CR,WR,FR)
      READ (5,105) (GRTGA,GRTGB,GRTDA,GRTDB)
      READ (5,110) (GRTGHP,GRTDHP)
      READ (5,115) (GRCG,GRCD,GRWG,GRWD,GRX)
      READ (5,120) (NYT,(NY(N),N=1,NYT))
```

```
100 FORMAT (4F10.0)
105 FORMAT (4F10.1)
110 FORMAT (2F10.1)
115 FORMAT (5F10.1)
120 FORMAT (1916)
    WRITE (6,140)
140 FORMAT ('1'///3X,'GROWTH RATES OF FARM EQUIPMENT POPULATIONS',
   1    ' (% PER YEAR) :'//31X,'GASOLINE',4X,'DIESEL'/)
    WRITE (6,145) (GRTGA,GRTDA,GRTGB,GRTDB)
145 FORMAT ('0',7X,'TRACTORS, 1973-1980',4X,F5.1,7X,F5.1/18X,
   1    '1981-1990',4X,F5.1,7X,F5.1)
    WRITE (6,150) (GRCG,GRCD)
150 FORMAT ('0',7X,'COMBINES',15X,F5.1,7X,F5.1)
    WRITE (6,155) (GRWG,GRWD)
155 FORMAT ('0',7X,'WINDROWERS',13X,F5.1,7X,F5.1)
    WRITE (6,160) (GRX,GRX)
160 FORMAT ('0',7X,'MISCELLANEOUS EQUIP',4X,F5.1,7X,F5.1///)
    WRITE (6,165)
165 FORMAT ('0',2X,'GROWTH RATES OF AVERAGE PTO HORSEPOWER ',
   1    '(% PER YEAR) :'/)
    WRITE (6,170) (GRTGHP,GRTDHP)
170 FORMAT ('0',7X,'GASOLINE TRACTORS',6X,F5.1//8X,
   1    'DIESEL TRACTORS',8X,F5.1)
C     PTO IS TRACTOR FLYWHEEL HP/POWER TAKE-OFF HP:
      PTO=1.15
C     AVG USAGE (HRS/YEAR):
      TGHR=340.
      TDHR=600.
      CHR=120.
      WHR=150.
      XHR=80.
```

```
C       AVG ENGINE HP:
        CHP=90.
        WHP=60.
        XHP=35.
C       AVG LOAD FACTOR:
        TLF=.57
        LF=.50
C       TRACTOR EMISSION FACTORS:
        TGEFHC=3.88
        TGEFCO=156.
        TGEFNO=7.27
        TGEFSO=.250
        TDEFHC=1.90
        TDEFCO=3.08
        TDEFNO=9.99
        TDEFSO=.879
C       NON-TRACTOR EMISSION FACTORS:
        GEFHC=7.59
        GEFCO=226.
        GEFNO=5.70
        GEFSO=.291
        DEFHC=1.83
        DEFCO=3.57
        DEFNO=9.09
        DEFSO=.914
C       GRAMS TO TONS CONVERSION FACTOR:
        CNST=1./(453.6*2000.)
```

```
GTGA=GRTGA/100.+1.
GTGB=GRTGB/100.+1.
GTDA=GRTDA/100.+1.
GTDB=GRTDB/100.+1.
GCG=GRCG/100.+1.
GCD=GRCD/100.+1.
GWG=GRWG/100.+1.
GWD=GRWD/100.+1.
GX=GRX/100.+1.
GTGHP=GRTGHP/100.+1.
GTDHP=GRTDHP/100.+1.
DO 700 I=1,18
IF (I .GE. 2) GO TO 200
TT(I)=TTR*4350000./4614550.
TG(I)=TT(I)*.641
TD(I)=TT(I)-TG(I)
TGHP(I)=36.
TDHP(I)=70.3
C(I)=CR*487000./467180.
CG(I)=C(I)*.85
CD(I)=C(I)-CG(I)
W(I)=(WR*12900./10120.)*.65
WG(I)=W(I)*.85
WD(I)=W(I)-WG(I)
X(I)=FR*1160000./2730250.
XG(I)=X(I)*.90
XD(I)=X(I)-XG(I)
GO TO 300
```

```
200 IF (I .GE. 9) GO TO 220
    TG(I)=TG(I-1)*GTGA
    TD(I)=TD(I-1)*GTDA
    GO TO 240
220 TG(I)=TG(I-1)*GTGB
    TD(I)=TD(I-1)*GTDB
240 TT(I)=TG(I)+TD(I)
    TGHP(I)=TGHP(I-1)*GTGHP
    TDHP(I)=TDHP(I-1)*GTDHP
    CG(I)=CG(I-1)*GCG
    CD(I)=CD(I-1)*GCD
    C(I)=CG(I)+CD(I)
    WG(I)=WG(I-1)*GWG
    WD(I)=WD(I-1)*GWD
    W(I)=WG(I)+WD(I)
    XG(I)=XG(I-1)*GX
    XD(I)=XD(I-1)*GX
    X(I)=XG(I)+XD(I)
300 HCTG(I)=TG(I)*TGHR*TGHP(I)*PTO*TLF*TGEFHC*CNST
    COTG(I)=TG(I)*TGHR*TGHP(I)*PTO*TLF*TGEFCO*CNST
    NOTG(I)=TG(I)*TGHR*TGHP(I)*PTO*TLF*TGEFNO*CNST
    SOTG(I)=TG(I)*TGHR*TGHP(I)*PTO*TLF*TGEFSO*CNST
    HCTD(I)=TD(I)*TDHR*TDHP(I)*PTO*TLF*TDEFHC*CNST
    COTD(I)=TD(I)*TDHR*TDHP(I)*PTO*TLF*TDEFCO*CNST
    NOTD(I)=TD(I)*TDHR*TDHP(I)*PTO*TLF*TDEFNO*CNST
    SOTD(I)=TD(I)*TDHR*TDHP(I)*PTO*TLF*TDEFSO*CNST
    HCTT(I)=HCTG(I)+HCTD(I)
    COTT(I)=COTG(I)+COTD(I)
    NOTT(I)=NOTG(I)+NOTD(I)
    SOTT(I)=SOTG(I)+SOTD(I)
```

```
HCCG(I)=CG(I)*CHR*CHP*LF*GEFHC*CNST                          141.000
COCG(I)=CG(I)*CHR*CHP*LF*GEFCO*CNST                          142.000
NOCG(I)=CG(I)*CHR*CHP*LF*GEFNO*CNST                          143.000
SOCG(I)=CG(I)*CHR*CHP*LF*GEFSO*CNST                          144.000
HCCD(I)=CD(I)*CHR*CHP*LF*DEFHC*CNST                          145.000
COCD(I)=CD(I)*CHR*CHP*LF*DEFCO*CNST                          146.000
NOCD(I)=CD(I)*CHR*CHP*LF*DEFNO*CNST                          147.000
SOCD(I)=CD(I)*CHR*CHP*LF*DEFSO*CNST                          148.000
HCWG(I)=WG(I)*WHR*WHP*LF*GEFHC*CNST                          149.000
COWG(I)=WG(I)*WHR*WHP*LF*GEFCO*CNST                          150.000
NOWG(I)=WG(I)*WHR*WHP*LF*GEFNO*CNST                          151.000
SOWG(I)=WG(I)*WHR*WHP*LF*GEFSO*CNST                          152.000
HCWD(I)=WD(I)*WHR*WHP*LF*DEFHC*CNST                          153.000
COWD(I)=WD(I)*WHR*WHP*LF*DEFCO*CNST                          154.000
NOWD(I)=WD(I)*WHR*WHP*LF*DEFNO*CNST                          155.000
SOWD(I)=WD(I)*WHR*WHP*LF*DEFSO*CNST                          156.000
HCXG(I)=XG(I)*XHR*XHP*LF*GEFHC*CNST                          157.000
COXG(I)=XG(I)*XHR*XHP*LF*GEFCO*CNST                          158.000
NOXG(I)=XG(I)*XHR*XHP*LF*GEFNO*CNST                          159.000
SOXG(I)=XG(I)*XHR*XHP*LF*GEFSO*CNST                          160.000
HCXD(I)=XD(I)*XHR*XHP*LF*DEFHC*CNST                          161.000
COXD(I)=XD(I)*XHR*XHP*LF*DEFCO*CNST                          162.000
NOXD(I)=XD(I)*XHR*XHP*LF*DEFNO*CNST                          163.000
SOXD(I)=XD(I)*XHR*XHP*LF*DEFSO*CNST                          164.000
HCNT(I)=HCCG(I)+HCCD(I)+HCWG(I)+HCWD(I)+HCXG(I)+HCXD(I)      165.000
```

```
      CONT(I)=COCG(I)+COCD(I)+COWG(I)+COWD(I)+COXG(I)+COXD(I)
      NONT(I)=NOCG(I)+NOCD(I)+NOWG(I)+NOWD(I)+NOXG(I)+NOXD(I)
      SONT(I)=SOCG(I)+SOCD(I)+SOWG(I)+SOWD(I)+SOXG(I)+SOXD(I)
      HC(I)=HCNT(I)+HCTT(I)
      CO(I)=CONT(I)+COTT(I)
      NO(I)=NONT(I)+NOTT(I)
      SO(I)=SONT(I)+SOTT(I)
      IY(I)=I+1972
      DO 350 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  350 CONTINUE
      GO TO 700
  400 WRITE (6,500) IY(I)
  500 FORMAT ('1',7X,'YEAR',I8//)
      WRITE (6,510)
  510 FORMAT ('0',37X,'FARM EQUIPMENT POPULATION'//34X,'GASOLINE',6X,
     1    'DIESEL',8X,'TOTAL'/)
      WRITE (6,515) (TG(I),TD(I),TT(I))
  515 FORMAT ('0',7X,'TRACTORS',17X,F8.0,5X,F8.0,5X,F8.0)
      WRITE (6,518) (TGHP(I),TDHP(I))
  518 FORMAT ('0',9X,'AVG PTO HP',16X,F5.1,8X,F5.1)
      WRITE (6,520) (CG(I),CD(I),C(I))
  520 FORMAT ('0',7X,'COMBINES, SELF PROP.',5X,F8.0,5X,F8.0,5X,F8.0)
      WRITE (6,525) (WG(I),WD(I),W(I))
  525 FORMAT ('0',7X,'WINDROWERS, SELF PROP.',3X,F8.0,5X,F8.0,5X,F8.0)
      WRITE (6,530) (XG(I),XD(I),X(I))
  530 FORMAT ('0',7X,'MISCELLANEOUS EQUIP',6X,F8.0,5X,F8.0,5X,F8.0///)
      WRITE (6,535)
  535 FORMAT ('0',45X,'EXHAUST EMISSIONS  (TONS PER YEAR)'//41X,'HC',
     1    12X,'CO',11X,'NOX',11X,'SOX'/)
      WRITE (6,540) (HCTG(I),COTG(I),NOTG(I),SOTG(I))
  540 FORMAT ('0',7X,'TRACTORS - GASOLINE',9X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
```

```
      WRITE (6,545) (HCTD(I),COTD(I),NOTD(I),SOTD(I))
  545 FORMAT ('0',7X,'TRACTORS - DIESEL',11X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,550) (HCTT(I),COTT(I),NOTT(I),SOTT(I))
  550 FORMAT ('0',9X,'TOTAL, TRACTORS',11X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0/)
      WRITE (6,555) (HCCG(I),COCG(I),NOCG(I),SOCG(I))
  555 FORMAT ('0',7X,'COMBINES - GASOLINE',9X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,560) (HCCD(I),COCD(I),NOCD(I),SOCD(I))
  560 FORMAT ('0',7X,'COMBINES - DIESEL',11X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,565) (HCWG(I),COWG(I),NOWG(I),SOWG(I))
  565 FORMAT ('0',7X,'WINDROWERS - GASOLINE',7X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,570) (HCWD(I),COWD(I),NOWD(I),SOWD(I))
  570 FORMAT ('0',7X,'WINDROWERS - DIESEL',9X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,575) (HCXG(I),COXG(I),NOXG(I),SOXG(I))
  575 FORMAT ('0',7X,'MISCELLANEOUS - GASOLINE',4X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,580) (HCXD(I),COXD(I),NOXD(I),SOXD(I))
  580 FORMAT ('0',7X,'MISCELLANEOUS - DIESEL',6X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,585) (HCNT(I),CONT(I),NONT(I),SONT(I))
  585 FORMAT ('0',9X,'TOTAL, NON TRACTOR EQUIP',2X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0/)
      WRITE (6,590) (HC(I),CO(I),NO(I),SO(I))
  590 FORMAT ('0',7X,'TOTAL EMISSIONS',13X,
     1    F8.0,6X,F8.0,6X,F8.0,6X,F8.0/////)
  700 CONTINUE
      END
```

APPENDIX 2

MERCHANT VESSELS

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

MERCHANT VESSELS

Variable Name	Description
JPORT	This index must be either 1,2, or 3; if JPORT=1, the AQCR has been designated as an ocean port; if JPORT=2; it is designated as a lake port; if JPORT=3, it is designated an an inland port
IBASE	Year of input data; must be either 1973 or 1974
MWW	The number of waterways in the AQCR for which vessel movement data are entered
GR	Projected growth rate of vessel traffic in the AQCR, in percent increase per year

For each of the "MWW" waterways the following three parameters must be entered:

Variable Name	Description
WMILES(M)	Waterway length, in miles
VTRIPS(M)	Total movements in the waterway in both directions of self-propelled tankers, cargo, and passenger ships
TTRIPS(M)	Total movements in the waterway in both directions of self-propelled tugs and towboats
NYT	Total number of years for which printed output is desired; must be 18 (17, if IBASE=1974) or less

Variable Name	Description
NY(N)	The years for which printed output is desired; must be between 1973 (1974, if IBASE=1974) and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	JPORT	I10	1
	IBASE	I10	11
	MWW	I10	21
	GR	F10.1	31
2,and as needed*	WMILES(M)	F10.1	1
	VTRIPS(M)	F10.0	11
	TTRIPS(M)	F10.0	21
2+MWW	NYT	I6	1
	NY(N)	I6	7,13,etc.

* Note: The three variables for each waterway are entered on a single data card. Therefore, the total number of cards containing WMILES(M), VTRIPS(M), TTRIPS(M) will be equal to MWW.

Merchant Vessel Computer Program Listing

```
C     ************  MERCHANT VESSEL PROGRAM  ************
C     'T' VARIABLES: TUGS & TOWBOATS
C     'V' VARIABLES: MOTORSHIPS & STEAMSHIPS
C     'D' VARIABLES: MOTORSHIPS
C     'S' VARIABLES: STEAMSHIPS
      DIMENSION IY(18),NY(18),THRS(18),DHRS(18),SHRS(18),
     1   THC(18),TCO(18),TNO(18),TSO(18),
     2   DHC(18),DCO(18),DNO(18),DSO(18),
     3   SHC(18),SCO(18),SNO(18),SSO(18),
     4   TOTHC(18),TOTCO(18),TOTNO(18),TOTSO(18),
     5   WMILES(99),TTRIPS(99),VTRIPS(99)
      REAL MPH
      READ (5,100) (JPORT,IBASE,MWW,GR)
  100 FORMAT (3I10,F10.1)
      TMILES=0.
      VMILES=0.
      DO 140 M=1,MWW
      READ (5,120) (WMILES(M),VTRIPS(M),TTRIPS(M))
  120 FORMAT (F10.1,2F10.0)
      VMILES=VMILES+(VTRIPS(M)*WMILES(M))
      TMILES=TMILES+(TTRIPS(M)*WMILES(M))
  140 CONTINUE
      READ (5,160) (NYT,(NY(N),N=1,NYT))
  160 FORMAT (19I6)
```

```
C     EMISSION FACTORS:
      TEFHC=14.8
      TEFCO=14.5
      TEFNO=26.9
      DEFHC=11.6
      DEFCO=12.9
      DEFNO=22.5
      SEFHC=.000158
      SEFCO=.00105
      SEFNO=.00533
C     AVG SPECIFIC FUEL RATE (LB/HP-HR):
      TFUEL=1.29
      DFUEL=1.06
      SFUEL=.52
C     AVG FUEL SULFUR CONTENT:
      TSULFR=.005
      DSULFR=.005
      SSULFR=.01
C     GRAMS TO TONS CONVERSION FACTOR:
      C=1./(453.6*2000.)
      G=GR/100.+1.
      DO 600 I=1,18
      IF (I .GE. 2) GO TO 300
      IF (JPORT-2) 200,220,240
C     OCEAN PORT PARAMETERS: AVG SPEED, HP, LOAD FACTOR
  200 SPH=8.
      THP=1800.
      TLF=.52
      DHP=6400.
      DLF=.45
      SHP=13800.
      SLF=.33
      THRS(I)=TMILES/MPH
      DMILES=VMILES*.89
      DHRS(I)=DMILES/MPH
      SMILES=VMILES-DMILES
      SHRS(I)=SMILES/MPH
      GO TO 320
C     LAKE PORT PARAMETERS: AVG SPEED, HP, LOAD FACTOR
  220 MPH=10.
      THP=1800.
      TLF=.52
      DHP=4000.
      DLF=.45
      SHP=4000.
      SLF=.45
      THRS(I)=TMILES/MPH
      DMILES=VMILES*.43
      DHRS(I)=DMILES/MPH
      SMILES=VMILES-DMILES
      SHRS(I)=SMILES/MPH
      GO TO 320
C     INLAND PORT PARAMETERS: AVG SPEED, HP, LOAD FACTOR
  240 MPH=8.
      THP=1800.
      TLF=.52
      DHP=1500.
      DLF=.45
      SHP=0.
      SLF=0.
      THRS(I)=TMILES/MPH
      DMILES=VMILES*1.
      DHRS(I)=DMILES/MPH
      SHRS(I)=0.
      GO TO 320
  300 THRS(I)=THRS(I-1)*G
      DHRS(I)=DHRS(I-1)*G
      SHRS(I)=SHRS(I-1)*G
  320 IF (IBASE .EQ. 1974) GO TO 330
      IY(I)=I+1972
      GO TO 340
  330 IY(I)=I+1973
  340 THC(I)=THRS(I)*THP*TLF*TEFHC*C
      TCO(I)=THRS(I)*THP*TLF*TEFCO*C
      TNO(I)=THRS(I)*THP*TLF*TEFNO*C
      DHC(I)=DHRS(I)*DHP*DLF*DEFHC*C
      DCO(I)=DHRS(I)*DHP*DLF*DEFCO*C
      DNO(I)=DHRS(I)*DHP*DLF*DEFNO*C
      SHC(I)=SHRS(I)*SHP*SLF*SEFHC*SFUEL/2000.
      SCO(I)=SHRS(I)*SHP*SLF*SEFCO*SFUEL/2000.
      SNO(I)=SHRS(I)*SHP*SLF*SEFNO*SFUEL/2000.
      TSO(I)=THRS(I)*THP*TLF*TFUEL*TSULFR*2./2000.
      DSO(I)=DHRS(I)*DHP*DLF*DFUEL*DSULFR*2./2000.
      SSO(I)=SHRS(I)*SHP*SLF*SFUEL*SSULFR*2./2000.
      TOTHC(I)=THC(I)+DHC(I)+SHC(I)
      TOTCO(I)=TCO(I)+DCO(I)+SCO(I)
      TOTNO(I)=TNO(I)+DNO(I)+SNO(I)
      TOTSO(I)=TSO(I)+DSO(I)+SSO(I)
      DO 360 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  360 CONTINUE
      GO TO 600
  400 WRITE (6,500) IY(I)
  500 FORMAT ('1',7X,'YEAR',I8//)
      WRITE (6,510)
  510 FORMAT ('0',35X,'ESTIMATED VESSEL - HOURS :'/)
      WRITE (6,515) (THRS(I),DHRS(I),SHRS(I))
  515 FORMAT ('0',7X,'TUG & TOWBOATS',51X,F8.0//8X,
     1   'MOTORSHIPS (DIESEL POWERED CARGO, TANKER & PASSENGER SHIPS)',
     2   6X,F8.0//8X,
     3   'STEAMSHIPS (STEAM POWERED CARGO, TANKER & PASSENGER SHIPS)',
     4   7X,F8.0////)
      WRITE (6,520)
  520 FORMAT ('0',43X,'EXHAUST EMISSIONS  (TONS PER YEAR)'//40X,
     1   'HC',12X,'CO',11X,'NOX',11X,'SOX'/)
      WRITE (6,525) (THC(I),TCO(I),TNO(I),TSO(I))
  525 FORMAT ('0',7X,'TUG & TOWBOATS',13X,
     1   F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,530) (DHC(I),DCO(I),DNO(I),DSO(I))
  530 FORMAT ('0',7X,'MOTORSHIPS',17X,
     1   F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,535) (SHC(I),SCO(I),SNO(I),SSO(I))
  535 FORMAT ('0',7X,'STEAMSHIPS',17X,
     1   F8.0,6X,F8.0,6X,F8.0,6X,F8.0/)
      WRITE (6,540) (TOTHC(I),TOTCO(I),TOTNO(I),TOTSO(I))
  540 FORMAT ('0',7X,'TOTAL EMISSIONS',12X,
     1   F8.0,6X,F8.0,6X,F8.0,6X,F8.0//////)
  600 CONTINUE
      END
```

APPENDIX 3

LOCOMOTIVES

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

LOCOMOTIVES

Variable Name	Description
JRUN	This index must be either 0 or 1; if 0, the program will estimate the miles of running track in the AQCR using the variables COUNTY, MANUF, and RETAIL; if 1, the user must directly input the miles of running track as RMILR
COUNTY	The number of counties in the AQCR; this variable is input only if JRUN=0
MANUF	The number of manufacturing establishments in the AQCR; this variable is input only if JRUN=0
RETAIL	The number of retail trade establishments in the AQCR; this variable is input only if JRUN=0
RMILR	The total miles of running track in the AQCR; this variable is input only if JRUN=1
KYARD	This index must be either 0 or 1; if 0, the user has designated that the AQCR has an average proportion of switchyard track and yard track mileage is set equal to 25% of running track mileage; if KYARD=1, the AQCR is designated as a major railroad terminal center and the program sets yard track mileage equal to running track mileage

Variable Name	Description
GR	Projected growth rate of railroad traffic in the AQCR, in percent increase per year
NYT	Total number of years for which printed output is desired; must be 18 or less
NY(N)	The years for which printed output is desired; must be between 1973 and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	JRUN	I2	1
If JRUN =0			
2	COUNTY	F10.0	1
	MANUF	F10.0	11
	RETAIL	F10.0	21
If JRUN=1			
2	RMILR	F10.1	1
3	KYARD	I2	1
	GR	F8.1	3
4	NYT	I6	1
	NY(N)	I6	7,13,etc

Locomotive Computer Program Listing

```
C     ************  LOCOMOTIVE PROGRAM  ************
C     'R' VARIABLES: LINE HAUL LOCOMOTIVES
C     'S' VARIABLES: SWITCHYARD LOCOMOTIVES
      DIMENSION IY(18),NY(18),RHR(18),SHR(18),R2HR(18),R4HR(18),
     1   S2HR(18),S4HR(18),RRHC(18),RRCO(18),RRNO(18),RRSO(18),
     2   RTHC(18),RTCO(18),RTNO(18),RTSO(18),R4HC(18),R4CO(18),R4NO(18),
     3   R4SO(18),S2HC(18),S2CO(18),S2NO(18),S2SO(18),S4HC(18),S4CO(18),
     4   S4NO(18),S4SO(18),R2HC(18),R2CO(18),R2NO(18),R2SO(18),RHC(18),
     5   RCO(18),RNO(18),RSO(18),SHC(18),SCO(18),SNO(18),SSO(18),
     6   THC(18),TCO(18),TNO(18),TSO(18)
      REAL MANUF,LOCOMI
      READ (5,100) (JRUN)
  100 FORMAT (I2)
      IF (JRUN .EQ. 1) GO TO 120
      READ (5,110) (COUNTY,MANUF,RETAIL)
  110 FORMAT (3F10.0)
      RMILR=(COUNTY*157.7)-(MANUF*.3944)+(RETAIL*.1488)
      GO TO 130
  120 READ (5,125) (RMILR)
  125 FORMAT (F10.1)
  130 READ (5,135) (KYARD,GR)
      READ (5,140) (NYT,(NY(N),N=1,NYT))
  135 FORMAT (I2,F8.1)
  140 FORMAT (19I6)
```

```
C     AVERAGE SPEED (MPH):
      SPEED=20.
C     1973 U.S. TRACK MILEAGE:
      RMILUS=284800.
      SMILUS=61780.
C     AVG ENGINE HP:
      RHP=2228.
      SHP=1091.
C     AVG LOAD FACTOR:
      RLF=.397
      SLF=.051
C     ROOTS-BLOWN 2-S LINE HAUL EMISSION FACTORS:
      RREFHC=3.95
      RREFCO=1.76
      RREFNO=9.45
C     TURBOCHRG 2-S LINE HAUL EMISSION FACTORS:
      RTEFHC=.695
      RTEFCO=4.00
      RTEFNO=8.22
C     TURBOCHRG 4-S LINE HAUL EMISSION FACTORS:
      R4EFHC=2.19
      R4EFCO=4.08
      R4EFNO=10.4
C     ROOTS-BLOWN 2-S SWITCH EMISSION FACTORS:
      S2EFHC=8.87
      S2EFCO=3.89
      S2EFNO=11.4
C     ROOTS-BLOWN 4-S SWITCH EMISSION FACTORS:
      S4EFHC=4.96
      S4EFCO=12.9
      S4EFNO=16.6
```

```
C     AVG SPECIFIC FUEL RATE (LB/HP-HR):
      RRFUEL=.419
      RTFUEL=.386
      R4FUEL=.347
      S2FUEL=.723
      S4FUEL=.532
C     AVG FUEL SULFUR CONTENT:
      SULFUR=.004
C     GRAMS TO TONS CONVERSION FACTOR:
      C=1./(453.6*2000.)
      G=GR/100.+1.
      IF (KYARD .EQ. 1) GO TO 220
      SMILR=RMILR*.25
      GO TO 230
  220 SMILR=RMILR
  230 DO 600 I=1,18
      IF (I .GE. 2) GO TO 250
C     MILES OF LINE HAUL OPERATION:
      LOCOMI=RMILR*1510000000./RMILUS
C     HOURS OF OPERATION:
      RHR(I)=LOCOMI/SPEED
      SHR(I)=SMILR*40830000./SMILUS
      GO TO 280
  250 RHR(I)=RHR(I-1)*G
      SHR(I)=SHR(I-1)*G
  280 R2HR(I)=RHR(I)*.4
      RWHR=2.*R2HR(I)
      P4HR(I)=RHR(I)*.2
      S2HR(I)=SHR(I)*.7
      S4HR(I)=SHR(I)*.3
```

```
RRHC(I)=R2HR(I)*RHP*RLF*RREFHC*C
RRCO(I)=R2HR(I)*RHP*RLF*RREFCO*C
RRNO(I)=R2HR(I)*RHP*RLF*RREFNO*C
RTHC(I)=R2HR(I)*RHP*RLF*RTEFHC*C
RTCO(I)=R2HR(I)*RHP*RLF*RTEFCO*C
RTNO(I)=R2HR(I)*RHP*RLF*RTEFNO*C
R4HC(I)=R4HR(I)*RHP*RLF*R4EFHC*C
R4CO(I)=R4HR(I)*RHP*RLF*R4EFCO*C
R4NO(I)=R4HR(I)*RHP*RLF*R4EFNO*C
S2HC(I)=S2HR(I)*SHP*SLF*S2EFHC*C
S2CO(I)=S2HR(I)*SHP*SLF*S2EFCO*C
S2NO(I)=S2HR(I)*SHP*SLF*S2EFNO*C
S4HC(I)=S4HR(I)*SHP*SLF*S4EFHC*C
S4CO(I)=S4HR(I)*SHP*SLF*S4EFCO*C
S4NO(I)=S4HR(I)*SHP*SLF*S4EFNO*C
RRSO(I)=R2HR(I)*RHP*RLF*RRFUEL*SULFUR*2./2000.
RTSO(I)=R2HR(I)*RHP*RLF*RTFUEL*SULFUR*2./2000.
R4SO(I)=R4HR(I)*RHP*RLF*R4FUEL*SULFUR*2./2000.
S2SO(I)=S2HR(I)*SHP*SLF*S2FUEL*SULFUR*2./2000.
S4SO(I)=S4HR(I)*SHP*SLF*S4FUEL*SULFUR*2./2000.
R2HC(I)=RRHC(I)+RTHC(I)
R2CO(I)=RRCO(I)+RTCO(I)
R2NO(I)=RRNO(I)+RTNO(I)
R2SO(I)=RRSO(I)+RTSO(I)
RHC(I)=R2HC(I)+R4HC(I)
```

```
      RCO(I)=R2CO(I)+R4CO(I)
      RNO(I)=R2NO(I)+R4NO(I)
      RSO(I)=R2SO(I)+R4SO(I)
      SHC(I)=S2HC(I)+S4HC(I)
      SCO(I)=S2CO(I)+S4CO(I)
      SNO(I)=S2NO(I)+S4NO(I)
      SSO(I)=S2SO(I)+S4SO(I)
      THC(I)=RHC(I)+SHC(I)
      TCO(I)=RCO(I)+SCO(I)
      TNO(I)=RNO(I)+SNO(I)
      TSO(I)=RSO(I)+SSO(I)
      IY(I)=I+1972
      DO 300 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  300 CONTINUE
      GO TO 600
  400 WRITE (6,500) IY(I)
  500 FORMAT ('1',7X,'YEAR',I8//)
      WRITE (6,510)
  510 FORMAT ('0',17X,'ESTIMATED LOCOMOTIVE - HOURS :'/)
      WRITE (6,515) (RWHR,R4HR(I))
  515 FORMAT ('0',7X,'LINE HAUL OPERATIONS'//10X,
     1    '2 STROKE UNITS',13X,F10.0//10X,'4 STROKE UNITS',13X,F10.0/)
      WRITE (6,520) (S2HR(I),S4HR(I))
  520 FORMAT ('0',7X,'SWITCHYARD ACTIVITIES'//10X,
     1    '2 STROKE UNITS',13X,F10.0//10X,'4 STROKE UNITS',13X,F10.0////)
      WRITE (6,525)
  525 FORMAT ('0',45X,'EXHAUST EMISSIONS  (TONS PER YEAR)'//41X,
     1    'HC',12X,'CO',11X,'NOX',11X,'SOX'/)
```

```
      WRITE (6,530) (R2HC(I),R2CO(I),R2NO(I),R2SO(I))
  530 FORMAT ('0',7X,'LINE HAUL OPERATIONS'//10X,'2 STROKE UNITS',
     1   12X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,535) (R4HC(I),R4CO(I),R4NO(I),R4SO(I))
  535 FORMAT ('0',9X,'4 STROKE UNITS',
     1   12X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,540) (RHC(I),RCO(I),RNO(I),RSO(I))
  540 FORMAT ('0',9X,'TOTAL',
     1   21X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0/)
      WRITE (6,545) (S2HC(I),S2CO(I),S2NO(I),S2SO(I))
  545 FORMAT ('0',7X,'SWITCHYARD ACTIVITIES'//10X,'2 STROKE UNITS',
     1   12X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,550) (S4HC(I),S4CO(I),S4NO(I),S4SO(I))
  550 FORMAT ('0',9X,'4 STROKE UNITS',
     1   12X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0)
      WRITE (6,555) (SHC(I),SCO(I),SNO(I),SSO(I))
  555 FORMAT ('0',9X,'TOTAL',
     1   21X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0/)
      WRITE (6,560) (THC(I),TCO(I),TNO(I),TSO(I))
  560 FORMAT ('0',7X,'TOTAL EMISSIONS',
     1   13X,F8.0,6X,F8.0,6X,F8.0,6X,F8.0////)
  600 CONTINUE
      END
```

APPENDIX 4

LAWN AND GARDEN IMPLEMENTS

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

LAWN AND GARDEN IMPLEMENTS

Variable Name	Description
OOHUR	Total number of owner-occupied housing units in the AQCR in 1970
B	Length of growing season, in months
GR	Projected growth rate of lawn and garden implements in the AQCR, in percent increase per year
NYT	Total number of years (seasons) for which printed output is desired; must be 17 or less
NY(N)	The years (seasons) for which printed output is desired; must be between 1974 and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	OOHUR	F10.0	1
	B	F10.1	11
	GR	F10.1	21
2	NYT	I6	1
	NY(N)	I6	7,13, etc.

Lawn and Garden Implement Computer Program Listing

```
C     ************  LAWN & GARDEN IMPLEMENT PROGRAM  ************
C     'U' VARIABLES: TOTAL WALK BEHIND MOWERS
C     'V' VARIABLES: 2-STROKE WALK BEHIND MOWERS
C     'W' VARIABLES: 4-STROKE WALK BEHIND MOWERS
C     'X' VARIABLES: RIDING MOWERS & GARDEN TRACTORS
C     'Y' VARIABLES: MOTOR TILLERS
C     'Z' VARIABLES: TOTAL IMPLEMENTS
      DIMENSION UPR(17),VPR(17),WPR(17),XPR(17),YPR(17),D2(10)
      DIMENSION USH(17),USC(17),USN(17),VSH(17),VSC(17),VSN(17),
     1   WSH(17),WSC(17),WSN(17),XSH(17),XSC(17),XSN(17),YSH(17),
     2   YSC(17),YSN(17),ZSH(17),ZSC(17),ZSN(17),IY(17),NY(17)
      READ (5,20) (OOHUR,H,GR)
      READ (5,40) (NYT,(NY(N),N=1,NYT))
   20 FORMAT (F10.0,F10.1,F10.1)
   40 FORMAT (18I6)
C     1974 U.S. IMPLEMENT POPULATION:
      UPN=35200000.
      XPN=6300000.
      YPN=3000000.
C     EMISSION FACTORS, 2-STROKE HC, CO, NOX, THEN 4-STROKE:
      F2H=214.
      F2C=486.
      F2N=1.58
      F4H=20.5
      F4C=295.
      F4N=4.34
```

```
C       AVG USAGE (HRS/MONTH):
        UH=10.
        XH=19.
        YH=7.
C       AVG FNGINE HP:
        UT=3.1
        XT=8.2
        YT=5.
C       AVG LOAD FACTOR:
        UL=.7
        XL=.5
        YL=.8
C       1974 OWNER OCCUPIED HOUSING UNITS IN U.S. :
        OOHUN=39885000.
        G1=GP/100.+1.
C       GRAMS TO TONS CONVERSION FACTOR:
        C=1./(453.6*2000.)
        DO 500 I=1,17
        IF (I .GE. 2) GO TO 100
        UPR(I)=UPN*OOHUR/OOHUN
        XPR(I)=XPN*OOHUR/OOHUN
        YPR(I)=YPN*OOHUR/OOHUN
        VPR(I)=UPR(I)*.05
        WPR(I)=UPR(I)-VPR(I)
        D2(I)=0.
        GO TO 300
  100   UPR(I)=UPR(I-1)*G1
        IF (I .GE. 11) GO TO 200
C       2-STROKE MOWER PHASE-OUT ROUTINE:
      D2(I)=.05-(.005*(I-1))
      VPR(I)=UPR(I)*D2(I)
      WPR(I)=UPR(I)-VPR(I)
      GO TO 250
  200 WPR(I)=UPR(I)
      VPR(I)=0.
  250 XPR(I)=XPR(I-1)*G1
      YPR(I)=YPR(I-1)*G1
  300 IY(I)=1973+I
      VSH(I)=VPR(I)*UH*B*UT*UL*E2H*C
      VSC(I)=VPR(I)*UH*B*UT*UL*E2C*C
      VSN(I)=VPR(I)*UH*B*UT*UL*E2N*C
      WSH(I)=WPR(I)*UH*B*UT*UL*E4H*C
      WSC(I)=WPR(I)*UH*B*UT*UL*E4C*C
      WSN(I)=WPR(I)*UH*B*UT*UL*E4N*C
      XSH(I)=XPR(I)*XH*B*XT*XL*E4H*C
      XSC(I)=XPR(I)*XH*B*XT*XL*E4C*C
      XSN(I)=XPR(I)*XH*B*XT*XL*E4N*C
      YSH(I)=YPR(I)*YH*B*YT*YL*E4H*C
      YSC(I)=YPR(I)*YH*B*YT*YL*E4C*C
      YSN(I)=YPR(I)*YH*B*YT*YL*E4N*C
      USH(I)=VSH(I)+WSH(I)
      USC(I)=VSC(I)+WSC(I)
      USN(I)=VSN(I)+WSN(I)
      ZSH(I)=USH(I)+XSH(I)+YSH(I)
      ZSC(I)=USC(I)+XSC(I)+YSC(I)
      ZSN(I)=USN(I)+XSN(I)+YSN(I)
      DO 350 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  350 CONTINUE
      GO TO 500
```

```
400 WRITE (6,410) IY(I)
410 FORMAT ('1',5X,'SEASON',I8//)
    WRITE (6,412)
412 FORMAT ('0',12X,'ESTIMATED IMPLEMENT POPULATION :')
    IF (I .GE. 11) GO TO 420
    WRITE (6,415) (VPR(I),WPR(I))
415 FORMAT ('0',8X,'2 STROKE WALK BEHIND MOWERS',9X,F8.0//9X,
   1    '4 STROKE WALK BEHIND MOWERS',9X,F8.0)
420 WRITE (6,425) (UPR(I),XPR(I),YPR(I))
425 FORMAT ('0',5X,'WALK BEHIND LAWN MOWERS',16X,F8.0//
   1    6X,'RIDING MOWERS & GARDEN TRACTORS',8X,F8.0//
   2    6X,'MOTOR TILLERS',26X,F8.0////)
    WRITE (6,430)
430 FORMAT ('0',46X,'EXHAUST EMISSIONS  (TONS PER SEASON)'//
   1    50X,'HC',12X,'CO',12X,'NOX'/)
    IF (I .GE. 11) GO TO 440
    WRITE (6,435) (VSH(I),VSC(I),VSN(I),WSH(I),WSC(I),WSN(I))
435 FORMAT ('0',7X,'2-S WALK BEHIND LAWN MOWERS',12X,F7.0,7X,F7.0,
   1    7X,F7.0//8X,'4-S WALK BEHIND LAWN MOWERS',12X,F7.0,7X,F7.0,7X,
   2    F7.0)
440 WRITE (6,445) (USH(I),USC(I),USN(I))
445 FORMAT ('0',5X,'WALK BEHIND MOWERS',23X,F7.0,7X,F7.0,7X,F7.0)
    WRITE (6,450) (XSH(I),XSC(I),XSN(I),YSH(I),YSC(I),YSN(I))
450 FORMAT ('0',5X,'RIDING MOWERS & GARDEN TRACTORS',10X,F7.0,7X,F7.0,
   1    7X,F7.0//6X,'MOTOR TILLERS',28X,F7.0,7X,F7.0,7X,F7.0//)
    WRITE (6,455) (7SH(I),ZSC(I),ZSN(I))
455 FORMAT ('0',5X,'TOTAL LAWN & GARDEN IMPLEMENTS',11X,F7.0,7X,F7.0,
   1    7X,F7.0///)
    WRITE (6,460) (H)
460 FORMAT ('0',5X,'SEASON LENGTH =  ',F4.1,'  MONTHS'/////)
500 CONTINUE
    END
```

APPENDIX 5

SNOWMOBILES

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

SNOWMOBILES

Variable Name	Description
SMREG(1)	Total number of snowmobiles registered in the AQCR
DENSTY	Human density of AQCR, in persons per square mile
B	Length of snowmobile season, in months
GR	Projected growth rate of snowmobile registrations in the AQCR, in percent increase per year
NYT	Total number of years (seasons) for which printed output is desired; must be 17 or less
NY(N)	The years (seasons) for which printed output is desired; must be between 1974 and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	SMREG(1)	F10.0	1
	DENSTY	F10.2	11
	B	F10.1	21
	GR	F10.1	31
2	NYT	I6	1
	NY(N)	I6	7,13,etc.

Snowmobile Computer Program Listing

```
C      *************  SNOWMOBILE PROGRAM  ************
       DIMENSION SMREG(17),HRS(17),IY(17),NY(17),IX(17),THC(17),TCO(17),
     1   TNO(17)
       READ (5,100) (SMREG(1),DENSTY,H,GR)
       READ (5,120) (NYT,(NY(N),N=1,NYT))
   100 FORMAT (F10.0,F10.2,F10.1,F10.1)
   120 FORMAT (18I6)
C      EMISSION FACTORS:
       EFHC=642.
       EFCO=996.
       EFNO=10.2
C      GRAMS TO TONS CONVERSION FACTOR:
       C=1./(453.6*2000.)
       G=GR/100.+1.
       DO 500 I=1,17
       IF (I .EQ. 1) GO TO 200
       SMREG(I)=SMREG(I-1)*G
C      ESTIMATE HRS OF SNOWMOBILE USE:
   200 HRS(I)=(SMREG(I)*58.498)-(DENSTY*7187.5)+4952400.
```

```
      IY(I)=1973+I
      IX(I)=IY(I)-1
      THC(I)=HRS(I)*EFHC*C
      TCO(I)=HRS(I)*EFCO*C
      TNO(I)=HRS(I)*EFNO*C
      DO 300 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  300 CONTINUE
      GO TO 500
  400 WRITE (6,410) IX(I),IY(I)
  410 FORMAT ('1',8X,'SEASON',I8,' - ',I4//)
      WRITE (6,420) (HRS(I))
  420 FORMAT ('0',8X,'ESTIMATED HOURS OF SNOWMOBILE USE :',F10.0////)
      WRITE (6,430)
  430 FORMAT ('0',8X,'EXHAUST EMISSIONS  (TONS PER SEASON)'/)
      WRITE (6,440) (THC(I),TCO(I),TNO(I))
  440 FORMAT ('0',16X,'HC',12X,F8.0//17X,'CO',12X,F8.0//17X,'NOX',11X,
     1   F8.0////)
      WRITE (6,450) (R)
  450 FORMAT ('0',8X,'SEASON LENGTH =  ',F4.1,'  MONTHS'/////)
  500 CONTINUE
      END
```

APPENDIX 6

OUTBOARD MOTORS

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

OUTBOARD MOTORS

Variable Name	Description
REGR	Total number of boats registered in AQCR in 1974
B	Length of boating season, in months
GR	Projected growth rate of outboard motors in AQCR, in percent increase per year
NYT	Total number of years (seasons) for which printed output is desired; must be 17 or less
NY(N)	The years (seasons) for which printed output is desired; must be between 1974 and 1990, inclusive

Data Card	Variable	Format Specification	Starting in Column
1	REGR	F10.0	1
	B	F10.1	11
	GR	F10.1	21
2	NYT	I6	1
	NY(N)	I6	7, 13, etc.

Outboard Motor Computer Program Listing

```
C     ************* OUTBOARD MOTOR PROGRAM ************
      DIMENSION OUTBR(17), THC(17), TCO(17), TNO(17), IY(17), NY(17)
      READ (5,100) (REGR,B,GR)
      READ (5,120) (NYT,(NY(N),N=1,NYT))
  100 FORMAT (F10.0,F10.1,F10.1)
  120 FORMAT (18I6)
C     EMISSION FACTORS:
      EFHC=26.87
      EFCO=68.9
      EFNO=.127
C     AVG ENGINE HP:
      HP=29.2
C     1974 U.S. BOAT REGISTRATIONS:
      REGN=6830500.
C     1974 U.S. OUTBOARD MOTOR POPULATION:
      OUTBN=7595000.
C     GRAMS TO TONS CONVERSION FACTOR:
      F=1./(453.6*2000.)
      G=GR/100.+1.
C     IF SEASON IS 6 MONTHS OR LESS USAGE = 50 HRS/SEASON
C     IF SEASON IS OVER 6 MONTHS USAGE = 75 HRS/SEASON
      IF (B-6.) 150,150,160
  150 HR=50.
      GO TO 170
  160 HR=75.
```

```
170 DO 500 I=1,17
    IF (I .GE. 2) GO TO 200
    OUTBR(I)=OUTBN*REGR/REGN
    GO TO 300
200 OUTBR(I)=OUTBR(I-1)*G
300 IY(I)=1973+I
    THC(I)=OUTBR(I)*HR*HP*EFHC*C
    TCO(I)=OUTBR(I)*HR*HP*EFCO*C
    TNO(I)=OUTBR(I)*HR*HP*EFNO*C
    DO 350 N=1,NYT
    IF (IY(I) .EQ. NY(N)) GO TO 400
350 CONTINUE
    GO TO 500
400 WRITE (6,410) IY(I)
410 FORMAT ('1',8X,'SEASON',I8//)
    WRITE (6,420) (OUTBR(I))
420 FORMAT ('0',8X,'ESTIMATED OUTBOARD MOTORS IN USE : ',F10.0////)
    WRITE (6,430)
430 FORMAT ('0',8X,'EXHAUST EMISSIONS  (TONS PER SEASON)'/)
    WRITE (6,440) (THC(I),TCO(I),TNO(I))
440 FORMAT ('0',16X,'HC',12X,F8.0//17X,'CO',12X,F8.0//17X,'NOX',11X,
   1   F8.0////)
    WRITE (6,450) (R)
450 FORMAT ('0',8X,'SEASON LENGTH =  ',F4.1,'  MONTHS'/////)
500 CONTINUE
    END
```

APPENDIX 7

TRANSPORT REFRIGERATION UNITS

FORMAT GUIDE FOR COMPUTER PROGRAM INPUT DATA

TRANSPORT REFRIGERATION UNITS

Variable Name	Description
TKR	Total number of trucks (all types) registered in the AQCR in 1974
GRST	Projected growth rate of the transport refrigeration unit population used in straight trucks, in percent increase per year
GRTR	Projected growth rate of the transport refrigeration unit population used in trailers, in percent increase per year
NYT	Total number of years for which printed output is desired; must be 17 or less
NY(N)	The years for which printed output is desired; must be between 1974 and 1990, inclusive

Date Card	Variable	Format Specification	Starting in Column
1	TKR	F10.0	1
	GRST	F10.1	11
	GRTR	F10.1	21
2	NYT	I6	1
	NY(N)	I6	7,13, etc.

Transport Refrigeration Unit Computer Program Listing

```
C      ************  TRANSPORT REFRIGERATION UNIT PROGRAM  ************
C      'TR' VARIABLES: TRAILER UNITS
C      'ST' VARIABLES: STRAIGHT TRUCK UNITS
C      'G' INDICATES GAS POWERED
C      'D' INDICATES DSL POWERED
       DIMENSION ST(17),TRD(17),TRG(17),TR(17),STHC(17),STCO(17),
     1   STNO(17),TRDHC(17),TRDCO(17),TRDNO(17),TRGHC(17),TRGCO(17),
     2   TRGNO(17),TGHC(17),TGCO(17),TGNO(17),TOTHC(17),TOTCO(17),
     3   TOTNO(17),IY(17),NY(17),STESH(17),TRDESH(17),TRGESH(17),
     4   TRESH(17)
       READ (5,100) (TKR,GRST,GRTR)
       READ (5,120) (NYT,(NY(N),N=1,NYT))
   100 FORMAT (F10.0,2F10.1)
   120 FORMAT (16I6)
C      1974 U.S. TRUCK REGISTRATIONS:
       TKN=23481000.
C      1974 U.S. REFRIGERATED UNIT POPULATION:
       STN=228730.
       TRN=103850.
C      AVG USAGE (HRS/YEAR):
       STHR=2500.
       TRHR=3000.
C      AVG ENGINE HP:
       GHP=11.75
       DHP=26.
```

```
C     AVG LOAD FACTOR:
      GLF=.5
      DLF=.4
C     EMISSION FACTORS:
      EFGHC=17.72
      EFGCO=306.
      EFGNO=4.36
      EFDHC=1.29
      EFDCO=3.88
      EFDNO=5.47
C     GRAMS TO TONS CONVERSION FACTOR:
      C=1./(453.6*2000.)
      GST=GRST/100.+1.
      GTR=GRTR/100.+1.
      DO 500 I=1,17
      IF (I .GE. 2) GO TO 200
      ST(I)=TKR*STN/TKN
      TR(I)=TKR*TRN/TKN
      TRD(I)=TR(I)*.95
      TRG(I)=TR(I)-TRD(I)
      GO TO 250
  200 ST(I)=ST(I-1)*GST
      TRD(I)=TRD(I-1)*GTR
      TRG(I)=TRG(I-1)*GTR
      TR(I)=TRD(I)+TRG(I)
  250 IY(I)=1973+I
      STESH(I)=ST(I)*STHR
      TRDESH(I)=TRD(I)*TRHR
      TRGESH(I)=TRG(I)*TRHR
      TRESH(I)=TRDESH(I)+TRGESH(I)
      STHC(I)=ST(I)*STHR*GHP*GLF*EFGHC*C
      STCO(I)=ST(I)*STHR*GHP*GLF*EFGCO*C
      STNO(I)=ST(I)*STHR*GHP*GLF*EFGNO*C
      TRDHC(I)=TRD(I)*TRHR*DHP*DLF*EFDHC*C
      TRDCO(I)=TRD(I)*TRHR*DHP*DLF*EFDCO*C
      TRDNO(I)=TRD(I)*TRHR*DHP*DLF*EFDNO*C
      TRGHC(I)=TRG(I)*TRHR*GHP*GLF*EFGHC*C
      TRGCO(I)=TRG(I)*TRHR*GHP*GLF*EFGCO*C
      TRGNO(I)=TRG(I)*TRHR*GHP*GLF*EFGNO*C
      TGHC(I)=STHC(I)+TRGHC(I)
      TGCO(I)=STCO(I)+TRGCO(I)
      TGNO(I)=STNO(I)+TRGNO(I)
      TOTHC(I)=TGHC(I)+TRDHC(I)
      TOTCO(I)=TGCO(I)+TRDCO(I)
      TOTNO(I)=TGNO(I)+TRDNO(I)
      DO 300 N=1,NYT
      IF (IY(I) .EQ. NY(N)) GO TO 400
  300 CONTINUE
      GO TO 500
  400 WRITE (6,405) IY(I)
  405 FORMAT ('1',8X,'YEAR',I8//)
      WRITE (6,410)
  410 FORMAT ('0',8X,'ESTIMATED HOURS OF TRANSPORT REFRIGERATION UNIT',
     1    1X,'OPERATION :'/)
      WRITE (6,415) (STESH(I))
  415 FORMAT ('0',10X,'UNITS IN STRAIGHT TRUCKS, GASOLINE POWERED',
     1    4X,F10.0)
```

```
      WRITE (6,420) (TRESH(I),TRDESH(I),TRGESH(I))
420 FORMAT ('0',10X,'UNITS IN TRAILERS, TOTAL',22X,F10.0//13X,
   1    'DIESEL POWERED',30X,F10.0//13X,'GASOLINE POWERED',28X,
   2    F10.0////)
      WRITE (6,425)
425 FORMAT ('0',50X,'EXHAUST EMISSIONS  (TONS PER YEAR)'//54X,
   1    'HC',11X,'CO',10X,'NOX')
      WRITE (6,430) (STHC(I),STCO(I),STNO(I))
430 FORMAT ('0',6X,'GASOLINE POWERED UNITS'//11X,
   1    'IN STRAIGHT TRUCKS',21X,
   2    F7.0,6X,F7.0,6X,F7.0)
      WRITE (6,435) (TRGHC(I),TRGCO(I),TRGNO(I))
435 FORMAT ('0',10X,'IN TRAILERS',28X,
   1    F7.0,6X,F7.0,6X,F7.0)
      WRITE (6,440) (TGHC(I),TGCO(I),TGNO(I))
440 FORMAT ('0',10X,'TOTAL',34X,
   1    F7.0,6X,F7.0,6X,F7.0/)
      WRITE (6,445) (TRDHC(I),TRDCO(I),TRDNO(I))
445 FORMAT ('0',8X,'DIESEL POWERED UNITS IN TRAILERS, TOTAL',2X,
   1    F7.0,6X,F7.0,6X,F7.0/)
      WRITE (6,450) (TOTHC(I),TOTCO(I),TOTNO(I))
450 FORMAT ('0',8X,'TOTAL EMISSIONS',26X,
   1    F7.0,6X,F7.0,6X,F7.0////)
500 CONTINUE
      END
```

LIST OF REFERENCES

PART 1. FARM EQUIPMENT

1. U.S. Congress. Senate. Committee on Agriculture and Forestry. The U.S. food and fiber sector: energy use and outlook, by The Economic Research Service, Dept., of Agriculture. Committee Print, 93d Cong., 2d sess., 1974. Washington, D.C.: Government Printing Office, 1974

2. U.S. Department of Agriculture. Agriculture statistics, 1973. Washington, D.C.: Government Printing Office.

3. Iowa Department of Agriculture. Eleventh biennial report, July 1, to June 30, 1973.

4. Iowa Department of Agriculture. Agriculture Statistics Division. Annual crop summary, 1974. Iowa Crop and Livestock Reporting Service, January 16, 1975.

5. Implement and Tractor. Issues of 21 November 1973, 31 January 1974, and 21 November 1974.

6. U.S. Department of Commerce. Bureau of the Census. Census of agriculture: 1969. vol. 1, Area reports, pt. 16, Iowa.

7. Iowa Department of Agriculture. Agricultural Statistics Division. Number and size of farms in Iowa. Iowa Crop and Livestock Reporting Service, 1972.

8. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 5, Heavy-duty farm, construction, and industrial engines, by Southwest Research Institute, San Antonio, Texas, 1973. Publication no. APTD-1494.

9. Hardwick, G.C., and Hudson, C.R. 1973. Farm and industrial tractors emission trends and their impact. SAE paper 730829. Society of Automotive Engineers, New York.

Farm Equipment (continued)

10. U.S. Department of Commerce. Bureau of the Census. Industry Division. *Current industrial reports.* Series MA-35A, *Farm machines and equipment*. 1960-73.

11. U.S. Department of Agriculture. Economic Research Service. *Power and equipment on farms in 1964, 48 States*, by P.E. Strickler. Statistical Bulletin No. 457. Washington D.C.: Government Printing Office, 1970.

12. Ricketts, C.J., and Weber, J.A. 1961. Tractor engine loading. *Agricultural Engineering*. 42:236-39.

13. Automotive Environmental Systems, Inc. 1973. *Uncontrolled vehicle emission study*. Westminster, California.

14. Weber, J.A., and Stahl, G.L. 1969. Optimizing carburetion and ignition for a farm tractor engine. *Agricultural Engineering*. 50:74.

15. Doss, H.J., and Pfister, R.G. 1972. *Nature and extent of farm machinery use in relation to frequency of accidents in Michigan and Ohio*. Agricultural Engineering Dept., Michigan State University, East Lansing, Michigan.

16. Bainer, R.; Kepner, R.A.; and Barger, E.L. *Principles of farm machinery.* New York: John Wiley & Sons, Inc. 1st ed. 1955. 2nd ed. 1972.

17. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the North Central Iowa AQCR, May 1, 1976." (Computer printout.)

PART 2. MERCHANT VESSELS

1. Maritime Association of the Port of New York. 1975. *Statistical review of the number of ships calling at the eleven major ports of the U.S. During 1974.* New York.

2. U.S. Department of the Army. Corps of Engineers. *Waterborne commerce of the United States, 1973*.

3. U.S. Coast Guard. Captain of the Port of New York, Governors Island. Telephone interview, 26 November and 1 December, 1975.

Merchant Vessels (continued)

4. Lloyd's Register of Shipping statistical tables 1973. London.

5. Record of the American Bureau of Shipping, 1973 Ship register, 2 vols. New York.

6. All about steam boilers. Marine Engineering/Log. vol. 79, February 1974.

7. U.S. Department of Transportation. Transportation System Center. River towboat air pollution-St. Louis, Missouri: an estimation, by Joseph C. Sturm. Cambridge, Massachusetts, 1974.

8. New York Towboat Harbor and Carrier Association, New York. Telephone interview, 15 December 1975.

9. U.S. Department of Transportation. U.S. Coast Guard. A study of stack emissions from Coast Guard cutters, by A.F. Souza. Report no. CG-D-13-73. Washington, D.C., 1973

10. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 1, Locomotive diesel engines and marine counterparts, by Southwest Research Institute, San Antonio, Texas, 1972. Publication no. APTD-1490.

11. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Compilation of air pollutant emission factors, 2nd ed., 1973. Publication no. AP-42.

12. Fox, W.J., and McBirnie, S.C. 1970. Marine steam engines and turbines. London: Newnes-Butterworths.

13. The Port Authority of New York and New Jersey. Foreign trade 74, the Port of New York and New Jersey. New York, 1974

14. Lake Carriers Association. Annual report, 1974. Cleveland, Ohio.

15. Glowacki, E. "An investigation of air pollution caused by vessels on the Detroit River." U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Ann Arbor, Michigan, 1972. (Typewritten.)

Merchant Vessels (continued)

16. The Port Authority of New York and New Jersey. Marine Terminal Facilities, New York. Interview, 23 October 1975.

17. Rotkin, C.E. Big river barge operations would stun Mark Twain. Smithsonian. August 1975, pp. 28-35.

18. Tugboat Annie goes big time. Forbes. 1 December 1975, p. 83.

19. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the New Jersey-New York-Connecticut AQCR, May 1, 1976." (Computer printout.)

PART 3. LOCOMOTIVES

1. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Guides for compiling a comprehensive emission inventory. Revised, 1973. Publication no. APTD-1135.

2. U.S. Interstate Commerce Commission. Bureau of Accounts. Transport statistics in the United States for the year ended 31 December 1973. Part 1, Railroads. Washington, D.C.

3. Association of American Railroads. Economic and Finance Department. Operating and traffic statistics, 1973. O.S. series no. 215. Washington, D.C.

4. U.S. Interstate Commerce Commission. Bureau of Accounts, Railroads. Washington, D.C. Telephone interview, 30 October 1974 and 23 April 1976.

5. Summary of diesel locomotive ownership on Jan. 1, 1973. Railway Locomotive and Cars. May 1973, pp. 14-26.

6. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 1, Locomotive diesel engines and marine counterparts, by Southwest Research Institute, San Antonio, Texas, 1972. Publication no. APTD-1490.

7. General Motors Corp. Electro-Motive Division. LaGrange, Illinois. Telephone interview, 18 November 1974.

Locomotives (continued)

8. Association of American Railroads et al. 1972. *Report on exhaust emissions of selected railroad diesel locomotives*.

9. General Motors Corp. Electro-Motive Division. 1972. *A progress report on Electro-Motive's emissions reduction program for diesel engines*. LaGrange, Illinois.

10. Rice, R.A. 1973. *Energy efficiencies of the transport systems*. SAE paper 730066. Society of Automotive Engineers, New York.

11. Association of American Railroads. *1974 annual report*. Washington, D.C.

12. Association of American Railroads. *Yearbook of railroad facts, 1975.* Washington, D.C.

13. U.S. Department of Commerce. Bureau of the Census. *County and city data book, 1972*. Washington, D.C.: Government Printing Office.

14. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the Metropolitan Chicago Interstate AQCR, May 1, 1976." (Computer printout.)

PART 4. LAWN AND GARDEN IMPLEMENTS

1. Consumer Product Safety Commission. *A survey to determine awareness, attitudes, and behavior toward safety of outdoor power equipment,* by Market Facts, Inc. Rockville, Maryland, 1975.

2. Outdoor Power Equipment Institute Inc. *Annual statistics releases,* 1969 through 1974. Washington, D.C.

3. Donahue, J.A. et al. 1972. *Small engine exhaust emissions and air quality in the United States.* SAE paper 720198. Society of Automotive Engineers, New York.

4. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. *Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines.* Part 4, *Small air-cooled spark ignition utility engines*, by Southwest Research Institute, San Antonio, Texas, 1973. Publication no. APTD-1493.

Lawn and Garden Implements (continued)

5. Briggs & Stratton Corporation, Milwaukee. Telephone interview. 28 August 1975.

6. Automotive Environmental Systems, Inc. 1973. Uncontrolled vehicle emission study. Westminster, California.

7. U.S. Department of Commerce. Bureau of the Census. Census of housing: 1970. vol.1, Housing characteristics for states, cities, and counties, pt. 1, U.S. summary; pt. 24, Michigan.

8. Outdoor Power Equipment Institute Inc., Washington, D.C. Correspondence from E.J. Mentz, 7 July 1975.

9. U.S. Department of Commerce. Bureau of the Census. Industry Division. Current industrial reports. Series MA-35L, Internal combustion engines. 1968-73.

10. Implement and Tractor. Issue of 31 January 1974.

11. Eccleston, B.H. and Hurn, R.W. 1972. Exhaust emissions from small utility, internal combustion engines. SAE paper 720197. Society of Automotive Engineers, New York.

12. U.S. Environmental Protection Agency. National Air Data Branch "Emissions report of the Metropolitan Detroit-Port Huron AQCR." Data from June 1975. (Computer printout.)

PART 5. SNOWMOBILES

1. International Snowmobile Industry Association. An assessment of the snowmobile manufacturing industry 1975-1979. Falls Church, Virginia.

2. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 7, Snowmobiles, by Southwest Research Institute, San Antonio, Texas, 1974. Publication no. APTD-1496.

3. Automotive Environmental Systems, Inc. 1973. Uncontrolled vehicle emission study. Westminster, California.

4. State of Michigan. Secretary of State Office. County snowmobile registration. Lansing, Michigan.

Snowmobiles (continued)

5. State of Minnesota. Department of Natural Resources. *County snowmobile registrations.* St. Paul, Minnesota.

6. State of Wisconsin. Department of Natural Resources. *County snowmobiles registrations*. Madison, Wisconsin.

7. Michigan Department of Natural Resources. *1973-74 snowmobile guide*. Lansing, Michigan.

8. Snow Sports Publications Inc. *1974 market study, an in-depth profile of one million households owning snowmobiles in North America*. Minneapolis, Minnesota.

9. The snowmobile owner 1972. *Snow Goer Trade.* vol. 6, August 1972, pp. 42-9.

10. Graham, G. Talk presented at the Fifth International Snowmobile Congress held at Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan, February 12-15, 1973.

11. Vila, J.J. and Klopchic, P. *Ontario's 1970 snowmobile study.* Proceedings of the 1971 Snowmobile and Off the Road Vehicle Research Symposium, M. Chubb, ed. East Lansing, Michigan, 1971.

12. Brown, T.L. and Hill, G.A. *The New York snowmobiler and the private landowner*. Proceedings of the 1971 Snowmobile and Off the Road Vehicle Research Symposium, D.F. Holecek, ed. East Lansing, Michigan, 1974.

13. Stahl, M. and Bess, F.H. *The snowmobiler and noise.* Proceedings of the 1973 Snowmobile and Off the Road Vehicle Research Symposium, D.F. Holecek, ed. East Lansing, Michigan, 1974.

14. Lanier, L. and Chubb, M. *Michigan's 1970 snowmobile study*. Proceedings of the 1971 Snowmobile and Off the Road Vehicle Research Symposium, M. Chubb, ed. East Lansing, Michigan, 1971.

15. Department of Natural Resources of Michigan, Minnesota, and Wisconsin, and Upper Great Lakes Regional Commission. *Three state snowmobile economic and preference survey*, by Gogebic Community College. Ironwood, Michigan, 1974.

16. International Snowmobile Industry Association, Minneapolis, Minnesota. Telephone interview, 23 April 1975.

Snowmobiles (continued)

17. International Snowmobile Industry Association. Annual geographical distribution report, March 1, 1972 through February 28, 1973. Minneapolis, Minnesota.

18. U. S. Department of Commerce. Bureau of the Census. County and city data book, 1972. Washington, D.C.: Government Printing Office.

19. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the Central Michigan AQCR." Data from June 1975. (Computer printout.)

PART 6. OUTBOARD MOTORS

1. Marex Marketing Department and the National Association of Engine and Boat Manufacturers. Boating 1975: a statistical report on America's top family sport. Chicago, Illinois.

2. U. S. Department of Transportation. Coast Guard. Boating statistics--1973. Report CG-357. Washington, D.C.

3. U.S. Department of Transportation. Coast Guard. Recreational boating in the continental United States in 1973: the nationwide boating survey. National Technical Information Service, Springfield, Virginia.

4. State of Michigan. Secretary of State Office. County boat registrations. Lansing, Michigan.

5. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 2, Outboard motors, by Southwest Research Institute, San Antonio, Texas, 1973. Publication no. APTD-1491.

6. U.S. Department of Transportation. Transportation System Center. U.S. Coast Guard pollution abatement program: a preliminary study of vessel and boat exhaust emissions, by R.A. Walter. Cambridge, Massachusetts, 1971.

7. Boating Industry Association and the National Association of Engine and Boat Manufacturers. Recreational boating and the fuel shortage. Chicago, Illinois, 1974.

Outboard Motors (continued)

8. Boating Industry Association, Chicago, Illinois. Telephone interview, 13 January 1976.

9. Outboard Marine Corporation, Milwaukee, Wisconsin. Telephone interview, 13 January 1976.

10. Weber, W.J., Jr.: Cole, D.E.; and Posner, J.C. *Analysis of emissions from outboard two cycle marine engines*. Environmental and Water Resources Engineering Laboratory and the Automotive Engineering Laboratory, The University of Michigan, Ann Arbor, Michigan.

11. U.S. Environmental Protection Agency. National Environmental Research Center. *Crankcase drainage from in-service outboard motors,* by Southwest Research Institute, San Antonio, Texas, 1974. Environmental Protection Technology Series EPA-670/2-74-092.

12. Outboard Marine Corporation, Milwaukee, Wisconsin. Correspondence from R.H. Lincoln, 13 January 1976. Includes outboard motor duty cycle data compiled by OMC for the Boating Industry Association.

13. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the Metropolitan Detroit-Port Huron AQCR." Data from June 1975. (Computer printout.)

PART 7. TRANSPORT REFRIGERATION UNITS

1. Moser, D.E. and Kriebel, W.R. 1969. *Refrigerated transportation by motor common carriers, a management inquiry*. University Extension Division, University of Missouri, Columbia, Missouri.

2. U.S. Department of Commerce. Bureau of the Census. Industry Division. *Current industrial reports.* Series MA-35M, *Mechanical refrigeration systems.* 1965-73.

3. U.S. Department of Commerce. Bureau of the Census. *Census of transportation*. vol 2, *Truck inventory and use survey*. 1967 and 1972 editions.

4. Motor Vehicle Manufacturers Association. *Motor truck facts.* 1974 and 1975 editions. Detroit, Michigan.

Transport Refrigeration Units (continued)

5. California Air Resources Board. Emissions Inventory Section, Sacramento. Telephone interview, 24 September 1975.

6. Tunnel Publications, Inc. Facts and figures on the refrigerated truck market, vol. 2, 1970. Houston, Texas.

7. Refrigerated truck line survey. Quick Frozen Foods. vol. 37, June 1975, p. 22.

8. Thermo King Corporation, Minneapolis, Minnesota. Correspondence from D. Palm, 13 June 1975, and telephone interview, 16 September 1975.

9. Thermo King Corporation. Trailer and truck refrigeration, 1975 sales brochure. Minneapolis, Minnesota.

10. Carrier Transicold Company. Truck and trailer refrigeration, 1974 sales brochure. Syracuse, New York.

11. Carrier Transicold Company, Syracuse, New York. Telephone interview, 17 September, 1975.

12. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 5, Heavy-duty farm, construction, and industrial engines, by Southwest Research Institute, San Antonio, Texas, 1973. Publication no. APTD-1494.

13. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. Exhaust emissions from uncontrolled vehicles and related equipment using internal combustion engines. Part 4, Small air-cooled spark ignition utility engines, by Southwest Research Institute, San Antonio, Texas, 1973. Publication no. APTD-1493.

14. U.S. Environmental Protection Agency. National Air Data Branch. "Emissions report of the Metropolitan Los Angeles AQCR, May 1, 1976." (Computer printout.)

PART 8. HELICOPTERS

1. U.S. Department of Transportation. Federal Aviation Administration FAA statistical handbook of aviation, 1973. Washington, D.C.: Government Printing Office.

Helicopters (continued)

2. Stuelpnagel, T.R. Future of the light turbine helicopter. Vertiflite. vol. 20, March/April 1974, p.6.

3. Civil Aeronautics Board. Handbook of airline statistics, 1973. Washington, D.C.: Government Printing Office.

4. Civil Aeronautics Board. Aircraft operating cost and performance report. Washington, D.C.: Government Printing Office.

5. The Port Authority of New York and New Jersey. Aviation Economics Division, New York. Interview. 23 October 1975.

6. New York Police Department. Aviation Section. Telephone interview 28 October 1975.

7. New York State Police. Aviation Division, Albany. Correspondence from Lt. S.R. Thomas, 30 October 1975.

8. New Jersey State Police, Trenton. Telephone interview, 28 October 1975.

9. Nassua County (New York) Police Department. Telephone interview, 28 October 1975.

10. Suffolk County (New York) Police Department. Telephone interview, 28 October 1975.

11. The Port Authority of New York and New Jersey. Aviation Economics Division. Monthly summary report of airport activities, New York region, December 1974.

12. East 34th Street Heliport, New York City. Telephone interview, 28 October 1975.

13. 60th Street Heliport, New York City. Telephone interview, 28 October 1975.

14. U.S. Department of Transportation. Federal Aviation Administration. Census of U.S. civil aircraft, 1973. Washington, D.C.: Government Printing Office.

15. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Compilation of air pollutant emission factors, 2nd ed., 1973. Publication no. AP-42.

Helicopters (continued)

16. Summa Corporation. Hughes Helicopters Division, Culver City, California. Correspondence from R.L. Parrish, 28 July 1975.

17. United Technologies Corporation. Sikorsky Aircraft Division, Stratford, Connecticut. Correspondence, 7 July 1975.

18. American Helicopter Association, Washington, D.C. Telephone interview, 7 November 1975.

19. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. File data for gas turbine aircraft engine emissions. Ann Arbor, Michigan.

20. Cornell Aeronautical Laboratory. 1971. *Analysis of aircraft exhaust emission measurements*. Publication no. PB 204 879. National Technical Information Service, Springfield, Virginia.

21. U.S. Environmental Protection Agency. Office of Mobile Source Air Pollution Control. File data for piston aircraft engine emissions. Ann Arbor, Michigan.